August 1956

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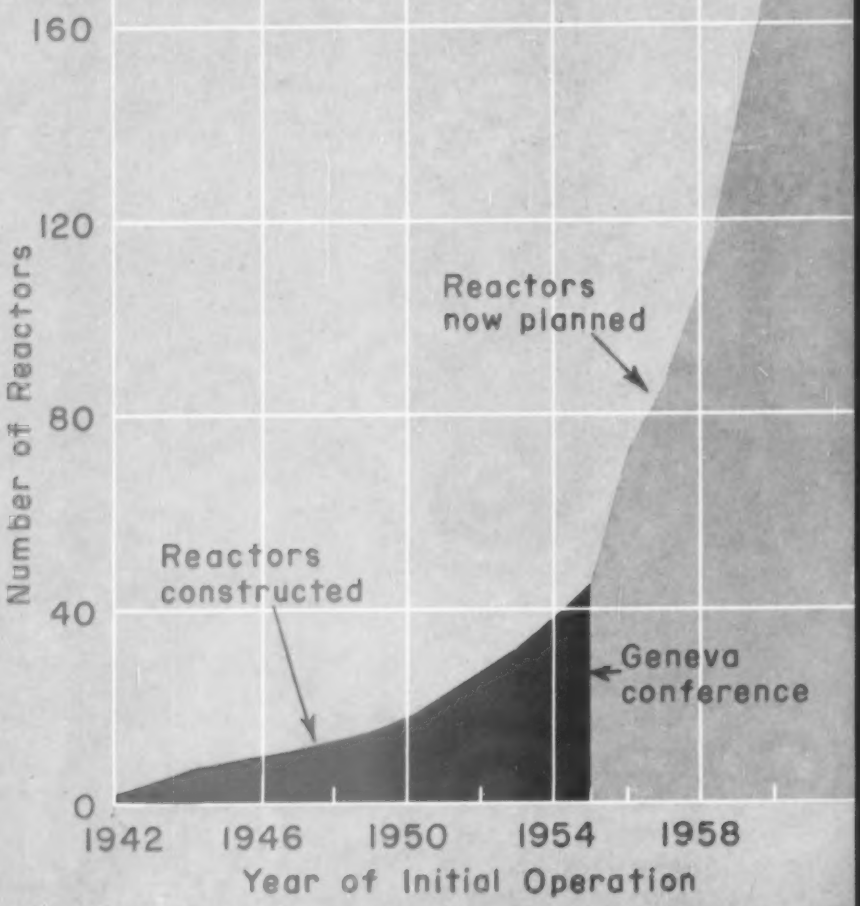
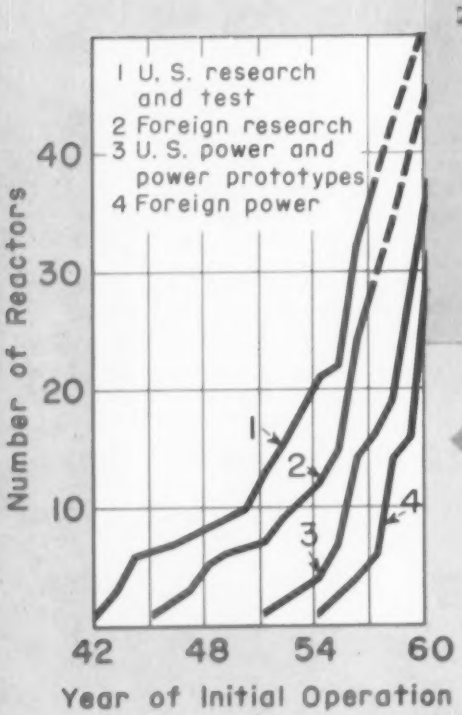
NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION





THESE DATA.....GIVE THIS TOTAL PICTURE

Reactor Projects Mushrooming

See page 30

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To determine nuclear reactor control element and mechanism operating characteristics during the design stage, General Electric engineers use this versatile test loop which simulates actual reactor conditions. In-service scram speeds, release times, reliability under adverse conditions, and mechanism life can be ascertained *before* the control drive is specified for a particular reactor.

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NUCLEONICS

AUGUST • 1956

Vol. 14, No. 8

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Where Reactor Development Stands Today... 30
J. A. LANE

Power and Research Reactors Move Into Hardware Stage... 38

Safe Containers Hold Organics for Irradiations... 54
N. P. SHIELLS, R. O. BOLT, and J. G. CARROLL

Tritium-Recoil Labeling of Organic Compounds... 58
F. S. ROWLAND and RICHARD WOLFGANG

The Case for Organic Coolant-Moderators for Power Reactors... 62
G. A. FREUND

Nomogram for Radioactivity Induced in Irradiation... 65
E. C. FREILING

Subcritical Reactor in a Pickle Barrel—NYU's Training Tool... 66
L. B. BORST

Mobile Laboratory Measures Fallout Activity... 69
R. L. MATHER, R. A. TAYLOR, and C. S. COOK

Indian Point Plant Nearing Construction Phase... 70

Who's Who in the Aircraft Nuclear Program... 74
J. E. KENTON

Cross Sections

Simple, Inexpensive Device Checks G-M Tube Operation... 79
F. E. ARMSTRONG

Radionuclides in Fused Enamel Make Stable Radiation Sources... 82
CLIFTON BLINCOE

CONTENTS Continued on Next Page

About NUCLEONICS

In the past several years, the peculiar characteristic of the peacetime nuclear industry was that words spoke louder than actions, there were lots of words—and most of them pointed to glowing pictures of the promise of the atom. Maybe the atom was even oversold.

But now the trend has turned. A trip across the country in June gave us a first-hand exciting picture of the metamorphosis that has taken place—the change from talk to action.

Although it may sound a bit anomalous, the best evidence of the change was at the phenominally successful second annual meeting of the American Nuclear Society in Chicago. There is, of course, lots of talk at conventions but the talk at this one was mostly about action. Take the two sessions on power and research reactor developments reported on page 38 of this issue. Along with the talk by Jim Lane of ORNL (page 30), this provided a dramatic demonstration that we're getting into the hardware stage and that before 1960 is over we'll have some pretty good insight into where we're going on the economics of nuclear power. By that

NUCLEONICS

CONTENTS Continued

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Scintillating Gels... 83
B. LIONEL FUNT

Diode-Phototube Monitor Uses Liquid Scintillator... 84
W. R. LAMB

Fast Differential Analyzer... 86
HAROLD A. LAMONDS

Continuous Alpha Air Monitor... 90
DAVID R. SAWLE

Calibrated Bench Used for Gamma Standardizing... 95
D. E. HULL and G. H. KEIRNS

Nuclear Engineering

Temperature Coefficient of Aircraft Shield Test Reactor... 98
J. C. NANCE

Reactor Two-Group Equations on UNIVAC Punch-Card Computer... 100
J. R. LAMARSH and S. S. RIDEOUT

Departments

ROUNDUP.....facing 18
EDITORIAL..... 29
TECHNICAL ADVANCES. 102
APPLIED RADIATION..... 103
BOOKS..... 104
PRODUCTS AND MATERIALS. 112
LETTERS..... 118
NEWSMAKERS..... 119
NUCLEAR CALENDAR. 120

About NUCLEONICS (Continued)

time, we'll have begun to accumulate operating data on almost every interesting reactor type.

The American Nuclear Society meeting itself, as a meeting, was testimony to the burgeoning activity in the nuclear field. Outside of last year's Geneva Conference, this was undoubtedly the best and most substantial unclassified, professional nuclear conference ever held. And the about-1,100 attendance consisted almost entirely of people actively working in the business.

The enthusiasm and vigor of the Chicago meeting provided a good jumping-off point for a tour of Western nuclear projects. Six years ago when we started making annual tours to the far West there was little more to do than spend time at universities, medical projects, and make token visits to Hanford and Idaho Falls. There was very little of interest going on of a nonmilitary nature and what there was was generally classified.

Today life in the nuclear West is a far cry from what it was in 1950. Apart from the attractions of the weather—and for New Yorkers it can be quite attractive—the West is vying for importance with the mid-West and East, particularly as far as industrial activity is concerned. San Francisco for example, has really blossomed out, both in reactor technology and radioisotope utilization. There are no less than nine nuclear industrial manufacturing or service organizations in the Bay area—General Electric Company with its new Atomic Power Equipment Department headquarters at San Jose, American Radiator and Standard Sanitary Corporation in Redwood City, Kaiser Engineers in Oakland, Bechtel Corporation in San Francisco, Aerojet-General Nucleonics in Walnut Creek, Tracerlab's Western Division in Richmond, Shell Development Company in Emeryville, California Research Corporation in Richmond and Stanford Research Institute in Palo Alto. All these outfits are producing action in the nuclear field.

Southern California has the giant Atomics International of North American Aviation Company in the Los Angeles area and the mysterious General Atomic Division of General Dynamics in San Diego. Although the AEC installations at Hanford and Idaho Falls are primarily concerned with military matters, they're now getting their fingers very deep into civilian work and, for example, have become prolific sources of unclassified papers.

These are all indicators of a growing industry.

•

We think the reactor report (p. 30–53) gives the best up-to-the minute picture available. Because we think our readers will agree, we're making single reprints available free. Just write to our Reprint Department for your copy.

—The Editors

VACUUM DRY BOX

APPLICATION AND GENERAL DESCRIPTION

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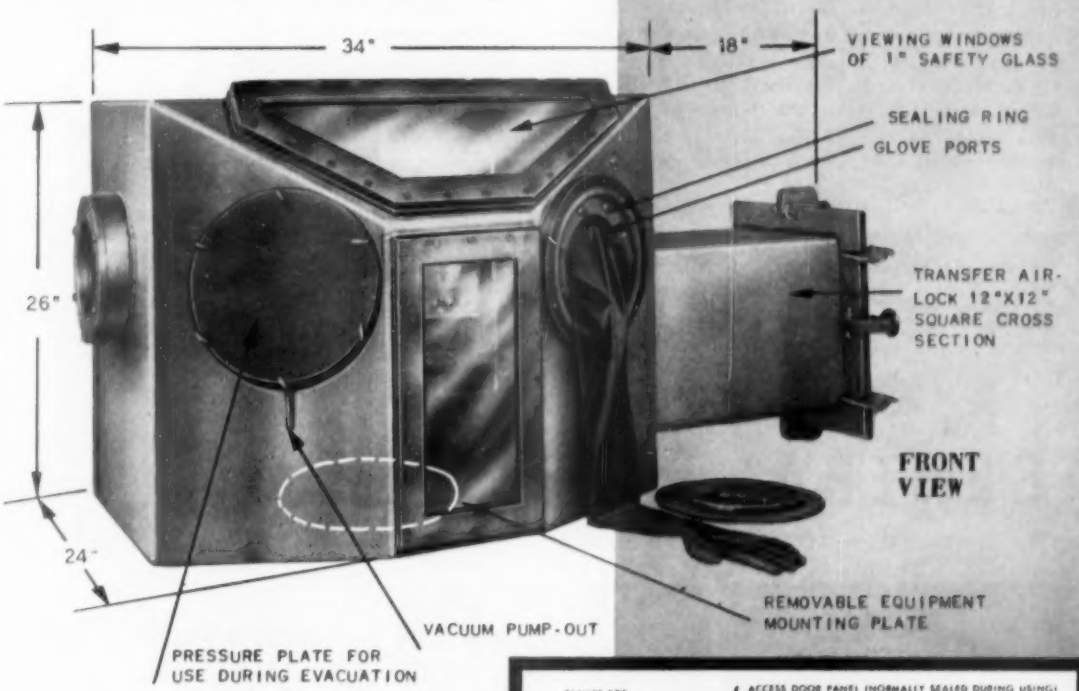
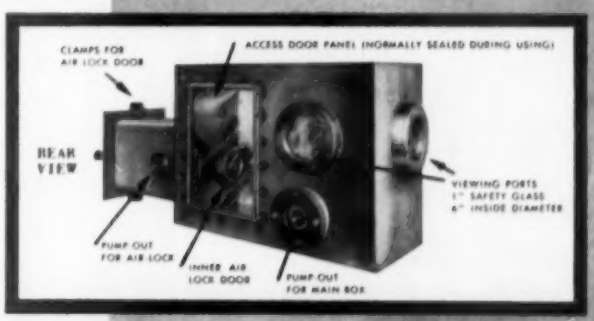
IN A CONTROLLED ATMOSPHERE

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This reactor uses fuel elements of the long-burnup type. Spent fuel elements are stored in the service pool adjacent to the reactor until cool enough for futher handling.

The reactor and service pool can be equipped for neutron and gamma irradiation for research without interfering with reactor operation.

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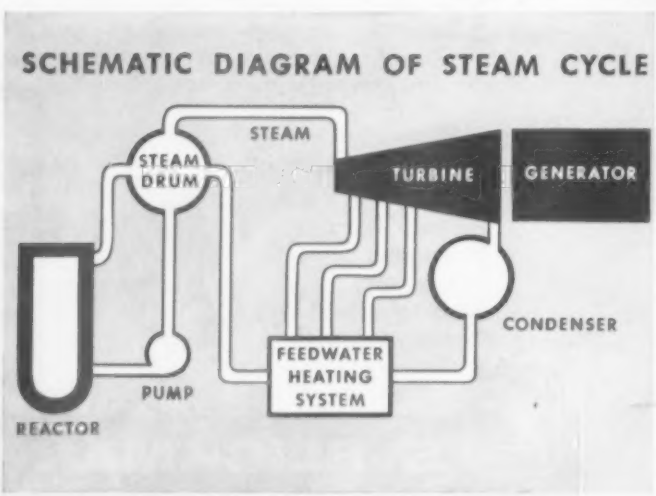
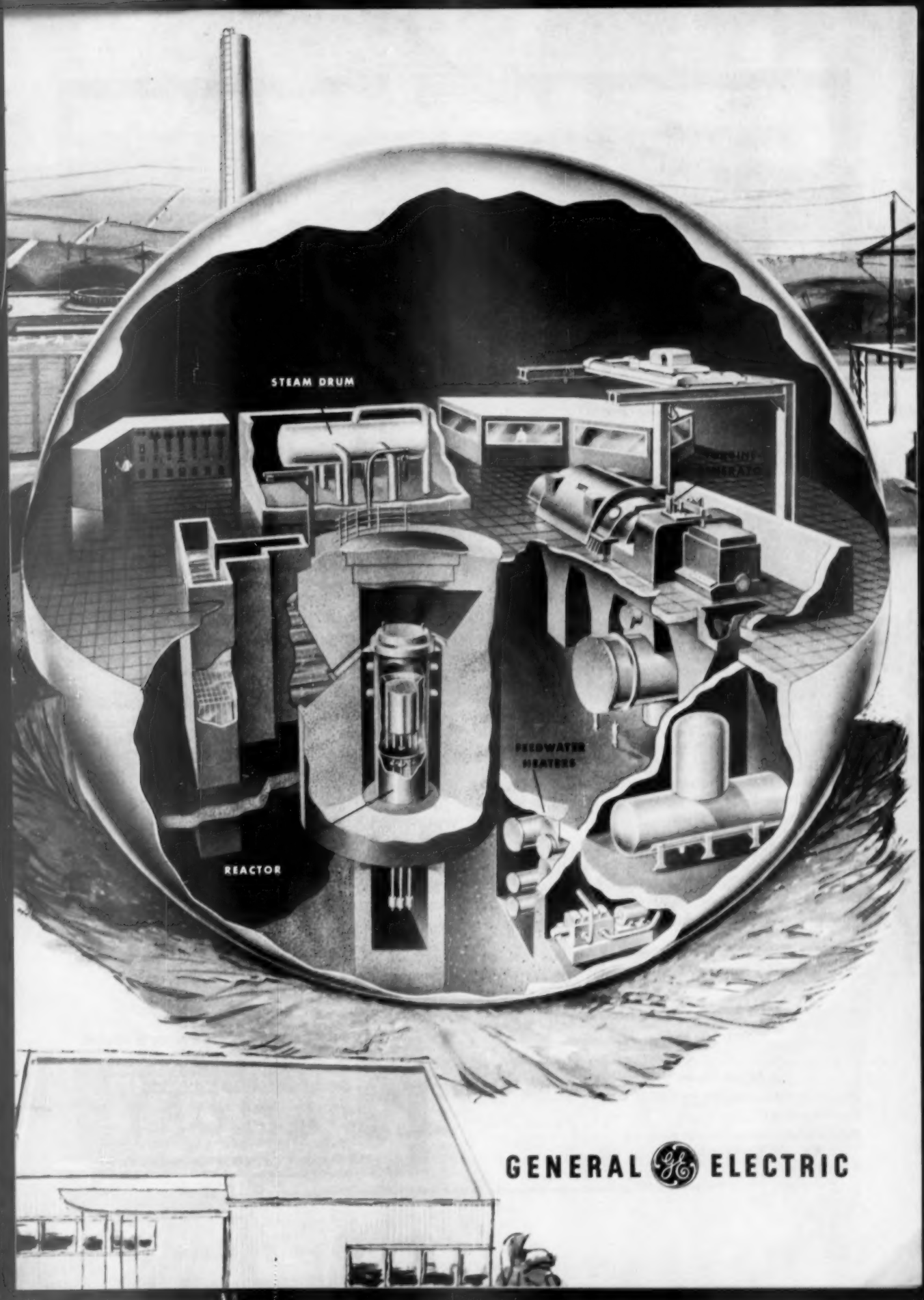
SIMULATED FUEL ELEMENT being installed in a heat transfer loop for tests under reactor thermal conditions. This is one of G.E.'s supporting atomic development programs to advance reactor design.



STEAM FLOWS FROM REACTOR to drum. Saturated steam passes to turbine; water goes to feedwater heaters and returns to steam drum. Forced circulation pump provides automatic control of response to load changes.



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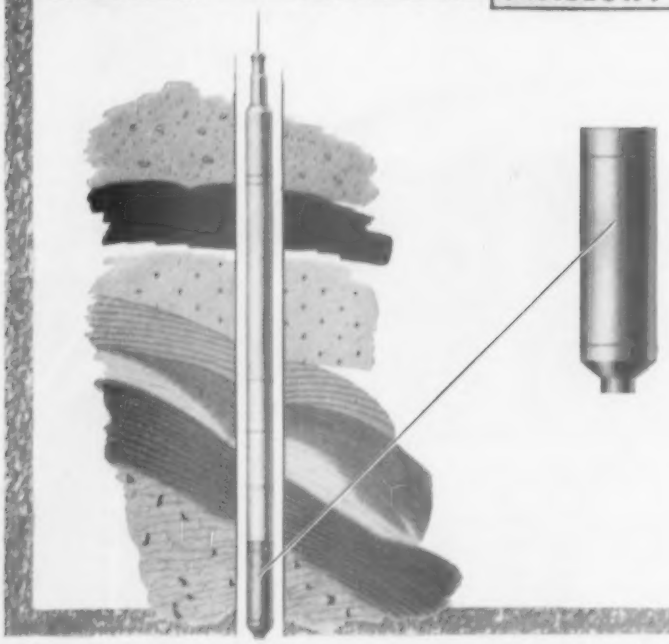

Small enough to lower inside a 2"-diameter oil well casing, logging unit developed by Perforating Guns Atlas Corp. has its radiation source shielded by Mallory 1000 Metal.

New oil well logging technique uses Mallory 1000 for radiation shielding

AN EXCEPTIONALLY ACCURATE method for examining oil wells for possible oil-rich strata has been developed recently by Perforating Guns Atlas Corporation. Based on simultaneous logging of gamma and neutron radiation, this equipment eliminates major sources of error in radiation logging. It is applied not only to new wells, but also to location of new producing levels in old wells.

To permit servicing of wells that already have small diameter casing or tubing installed, the logging unit is designed with an outside diameter of only 1¾". At its lower tip, a precisely machined cylinder of Mallory 1000 metal holds the radioactive source.

Use of this highly efficient shielding material provides, in the limited space available, effective suppression of undesirable radiation in unwanted directions. Exceptionally uniform in density, and free from internal voids that would detract from absorptive qualities, Mallory 1000 assures predictable performance essential to overall precision of measurement. It is readily machined to the close tolerances required. And its mechanical strength and weathering properties meet every requirement of this work.

Mallory 1000, a unique product of Mallory powder metallurgy, is proved by test and extensive use to be up to 30% more effective than lead in shielding radiation up to MEV levels. Its extreme density and high mechanical strength also make it valuable for counterweights, gyroscope rotors and similar mass components. Write to Mallory today for complete technical data and absorption characteristics.

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Friday—Sept. 28	9 a.m. to 3 p.m.

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Admission to sessions of the three-day Forum conference on "management and technology for the atomic industry" at the Morrison Hotel, Chicago, September 25-27, may be obtained by payment of a registration fee. A program of conference sessions and a schedule of charges are available from the Forum at:

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- Serves management as a gathering and distributing center of atomic energy information.
- Promotes understanding of the managerial, legal, economic, and technical problems which atomic energy presents.
- Encourages the development and adoption of standards and procedures which will facilitate full-scale development of atomic energy, including those standards which will assure maximum public and employee health and safety.
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- Coordinates efforts to find solutions to such problems as those having to do with reactor materials, insurance coverage and the establishment of uniform standards in the field of atomic energy.
- Cooperates with interested persons and agencies in the training of industrial personnel in the techniques of atomic energy.
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The Atomic Industry:

The nuclear reactors now being built or on the drawing boards, the fuel fabricating and reprocessing plants, the critical facilities and "hot" labs are key elements of the international atomic industry.

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Survey & Monitoring Equipment
Recording Instruments
Shielding & Safety Devices
Particle Accelerators
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In addition, those products and services that relate to the application of radiation to manufacturing, chemical processes, research, agriculture, medicine and food sterilization will be on view at the Fair.

See Trade Fair Preview in September's Nucleonics —

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September 24, 25, 26, 27 and 28

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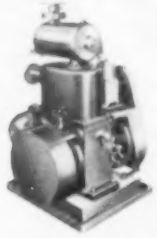
SAVE MAN-HOURS WITH HIGH VACUUM COMPONENTS MADE BY MEN WHO USE THEM

Mechanical Vacuum Pumps



NRC Model 100M

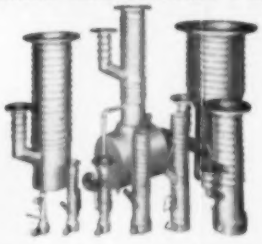
Because of the Gas Ballast feature, these pumps maintain their original high efficiency even when pumping 100% water, or other condensable vapors. Therefore, expensive oil purifiers and frequent and costly oil changes are not needed. NRC pumps have paid for themselves in three years from oil savings alone.

Model	Capacity CFM	Ultimate Vacuum Gas Ballast Off mm. Hg (A)	Ultimate Vacuum Gas Ballast On mm. Hg (A)	Price (B)
SINGLE STAGE				
2-S	1.25	3×10^{-3}	Less than one half millimeter of mercury	$155
4-S	3.3	3×10^{-3}		225
6-S	6.75	3×10^{-3}		312
15-S	11.6	3×10^{-2}		475
30-S	29.5	3×10^{-3}		800
100-S	100	3×10^{-3}		1475
200-S	202	1×10^{-2}		2500
400-S	403	5×10^{-3}		3875
DOUBLE STAGE				
2D	1.25	5×10^{-5}	2.5×10^{-2}	$215
4D	3.3	5×10^{-5}	2.5×10^{-2}	280
6D	6.75	5×10^{-5}	2.5×10^{-2}	425
15D	14.75		2.5×10^{-2}	750
30M	29.5	3×10^{-3}	3×10^{-3}	1200
100M	100	3×10^{-3}	3×10^{-3}	1975
200M	202	3×10^{-3}	3×10^{-3}	3200
400M	403	3×10^{-3}	3×10^{-3}	5425

Note A: McLeod gauge reading

Note B: F.O.B. Newton, Mass. Price includes pump, base, v-belt drive, and motor

Diffusion and Booster Pumps



NRC Booster and Diffusion Pumps

While NRC high vacuum diffusion and booster pumps are unsurpassed for through-put, blank off, and forepressure tolerance, they are especially outstanding for reliability. They offer long, trouble-free life, and are easy to maintain. Narcoil pumping fluids are unusually stable, have excellent pumping characteristics, and are low-priced. Narcoil-10 is $10.50 per gallon and Narcoil-40 is $38.50 per gallon.

Model	Blank-Off, mm. Hg (C)	Max. Speed Liters/Sec.	Tolerable Forepressure mm. Hg	Pumping Fluid	Price (D)
DIFFUSION PUMPS					
G-2-M (A)	8×10^{-7}	30	0.50	Mercury	$225
H-2-P	2×10^{-7}	80	0.25	Narcoil 40	125
A-2-P (B)	2×10^{-6}	85	0.20	DC 703	150
H-4-P	5×10^{-7}	300	0.31	Narcoil 40	245
H-6-P	5×10^{-7}	730	0.20	Narcoil 40	410
H-10-P	5×10^{-7}	1900	0.19	Narcoil 40	745
H-16-P	5×10^{-7}	5500	0.30	Narcoil 40	1320
BOOSTER PUMPS					
B-1	1×10^{-4}	8	0.30	Narcoil 10	$ 65
B-2	1×10^{-4}	85	0.85	Narcoil 10	195
B-4	1×10^{-4}	260	1.30	Narcoil 10	355
B-6	1×10^{-4}	530	0.90	Narcoil 10	990
B-12	1×10^{-4}	3500	0.90	Narcoil 10	on request

Note A: Glass pump

Note B: Air-cooled. Price includes blower

Note C: Untrapped ion gauge, except for G-2-M

Note D: Includes initial charge of pumping fluid

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510	Alphatron® Ionization	10^{-3} to 10.	520.00
515	Logarithmic Alphatron® Ionization	10^{-3} to 10.	250.00
561	Pirani	10^{-3} to 1.0	175.00
520	Alphatron® Ionization	10^{-4} to 10^{3}	550.00
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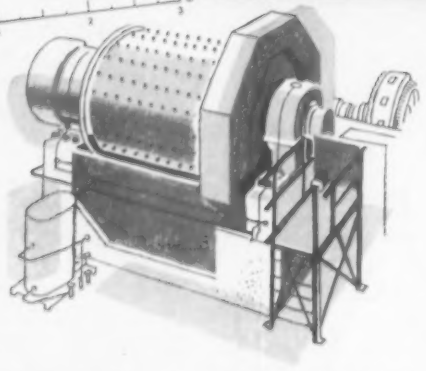

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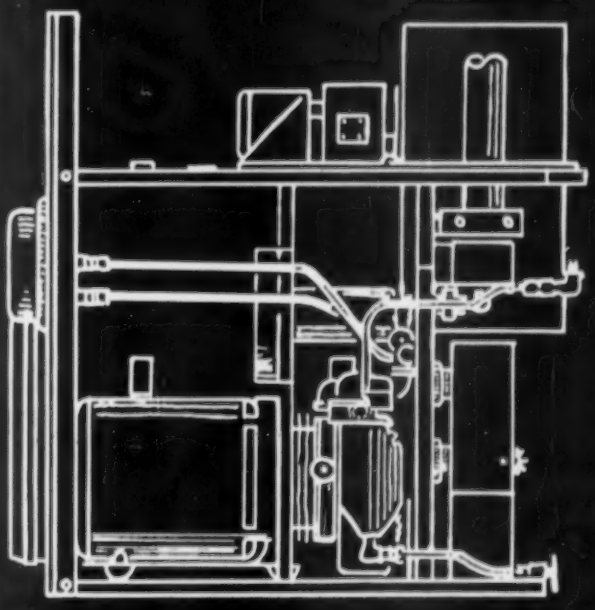

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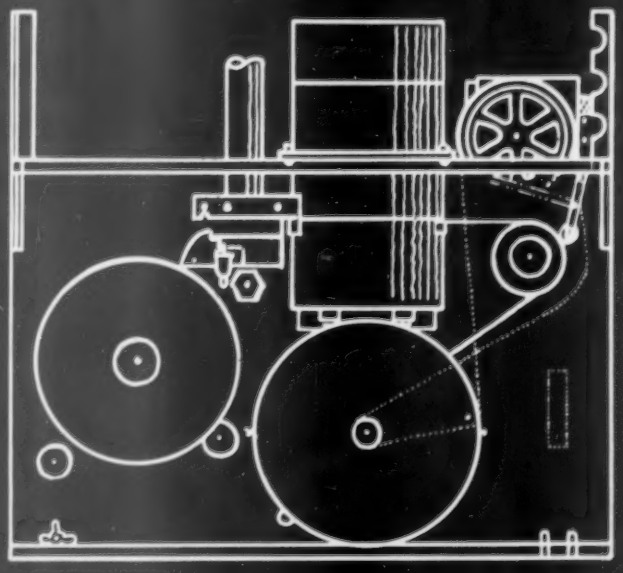

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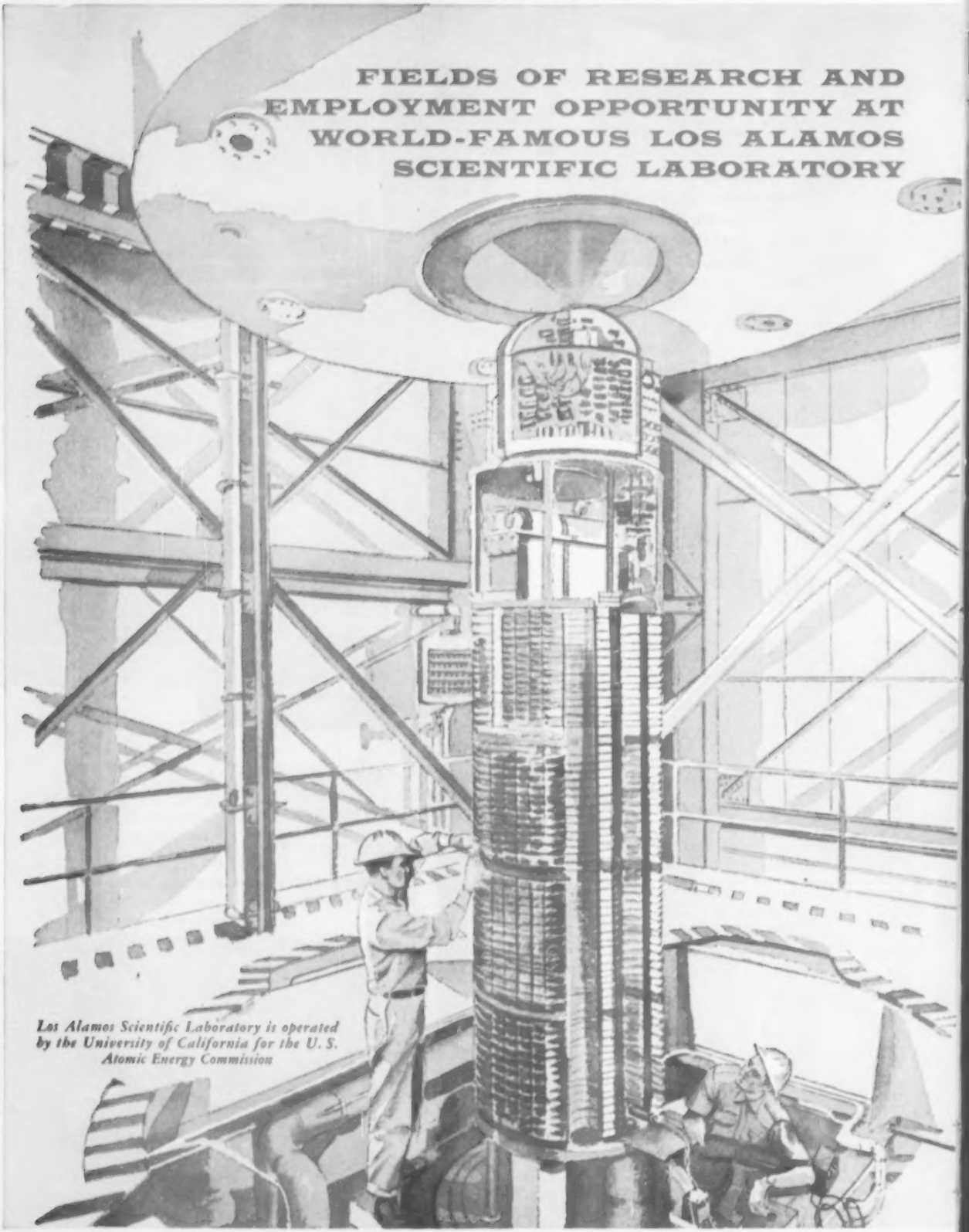
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Theoretical Physics and Mathematics

In the field of theoretical physics, the Laboratory carries on studies of nuclear theory, equations of state, mathematical analysis methods, hydrodynamics problems and various aspects of applied mathematics. The Theoretical Division is also concerned with the conceptual design of nuclear weapons, and supports many non-weapons activities such as the nuclear reactor and propulsion programs. The equipment used includes the Los Alamos-developed Maniac, the Maniac II, two IBM 704's and an IBM 701.

Experimental Nuclear Physics

Much of the work in experimental physics is concerned with nuclear properties of various materials. Fundamental studies are made of nuclear forces, neutron and charged-particle reactions and cross sections. Experimentation in controlled thermonuclear reactions is assuming increasing importance. Among the facilities available are three Van de Graaffs, two Cockcroft-Walton machines and a variable energy cyclotron.

Electronics and Instrumentation

The Laboratory is engaged in the design and development of nuclear physics research instruments, scintillation counters, fast pulse amplifiers, multi-channel analyzers, fast oscilloscopes, radiation detection instruments, electronic controls and control systems, and high-speed cameras which operate at 15 million frames per second. Electronics specialists also assist in the design of digital computers and of instruments for studying nuclear and thermonuclear detonations.

Nuclear Reactor Research

In connection with the peacetime applications of nuclear energy, the Laboratory is currently developing several advanced power reactors of unusual design. In addition, two research reactors are available for experimental studies. The remotely controlled critical assembly machines, known as Topsy , Godiva and Jezebel, constitute neutron research tools of a unique character.

Nuclear Propulsion

The Laboratory is actively engaged in the application of nuclear energy to the new and challenging field of self-propelled mobile reactors. There are studies in progress relative to engine design, heat transfer, controls and instrumentation.

Chemistry

Research in chemistry is devoted largely to inorganic and physical studies, especially of materials such as uranium, plutonium, deuterium and tritium used in nuclear energy systems. Radiochemical methods are applied in various investigations. Much work is being done on reaction kinetics, the effects of radiation on chemical reactions, complex ion formation and the determination of heats of combustion and solution. Extensive analytical studies include the use of a great variety of instruments, as well as the techniques of microanalysis.

Metallurgy and Metallurgical Engineering

Research activity and development in this field includes investigation of the metallurgical properties of materials used in nuclear energy systems; studies of extremely refractory substances, ceramics, cermets and plastics; the behavior of materials under extremely high temperatures and high pressures; studies of the properties of plutonium and its alloys, with increasing reference to their use in reactors, and of uranium and its alloys; development of fabrication techniques for various metals and alloys; and the high temperature properties of refractory metals tungsten, molybdenum, columbium, etc.

Weapons Physics, Design and Testing

Still the nation's principal institution for nuclear and thermonuclear weapons research, the Laboratory takes nuclear weapons from the concept stage to proved performance as determined by field tests. Activities in weapons research and development include the mechanics and dynamics of initiating a nuclear energy release; the behavior of supercritical systems; the testing of nuclear devices and weapons assemblies in Nevada and in the Pacific; engineering design of tests and prototypes of nuclear systems; and the design and development of nuclear weapons components and the techniques for their manufacture.

Explosives Research and Development

Work in this field includes study of fabrication, storage and stability problems of explosives; making and evaluating novel organic chemical compounds of possible use as explosives; mechanics and dynamics of explosive phenomena; and physical and chemical properties of explosive material using mass spectrometer, infra-red spectrometer, X-ray equipment and other analytical techniques. High explosives are employed in research on equations of state and shock wave phenomena.

Mechanical Engineering

Design and development work is carried on in connection with weapons design, field test facilities, the power reactor and propulsion programs, servo-mechanisms and remote control systems. High explosives systems are designed and manufactured. Other types of work are estimating, cost analysis and liaison between architectural engineers and contractors.

Chemical Engineering

Chemical engineering work includes studies of heat transfer, fluid flow, solvent extraction, evaporation, distillation and systems at extreme temperatures and pressures. Problems supporting inorganic and physical chemistry research projects are also undertaken. Other activities are the remote control handling of radioactive materials and corrosion and erosion studies.

Electrical Engineering

Much effort is devoted to the design of induction heating systems for study of alloys at extremely high temperatures; of DC power supplies at currents up to 100,000 amperes; of servo-mechanism controls for nuclear reactors; and of high magnetic field systems. Work is done in planning, building and installing power distribution systems and their controls.

The Laboratory now has staff openings for technically qualified people interested in these fields of research and development. For additional information address your inquiry to

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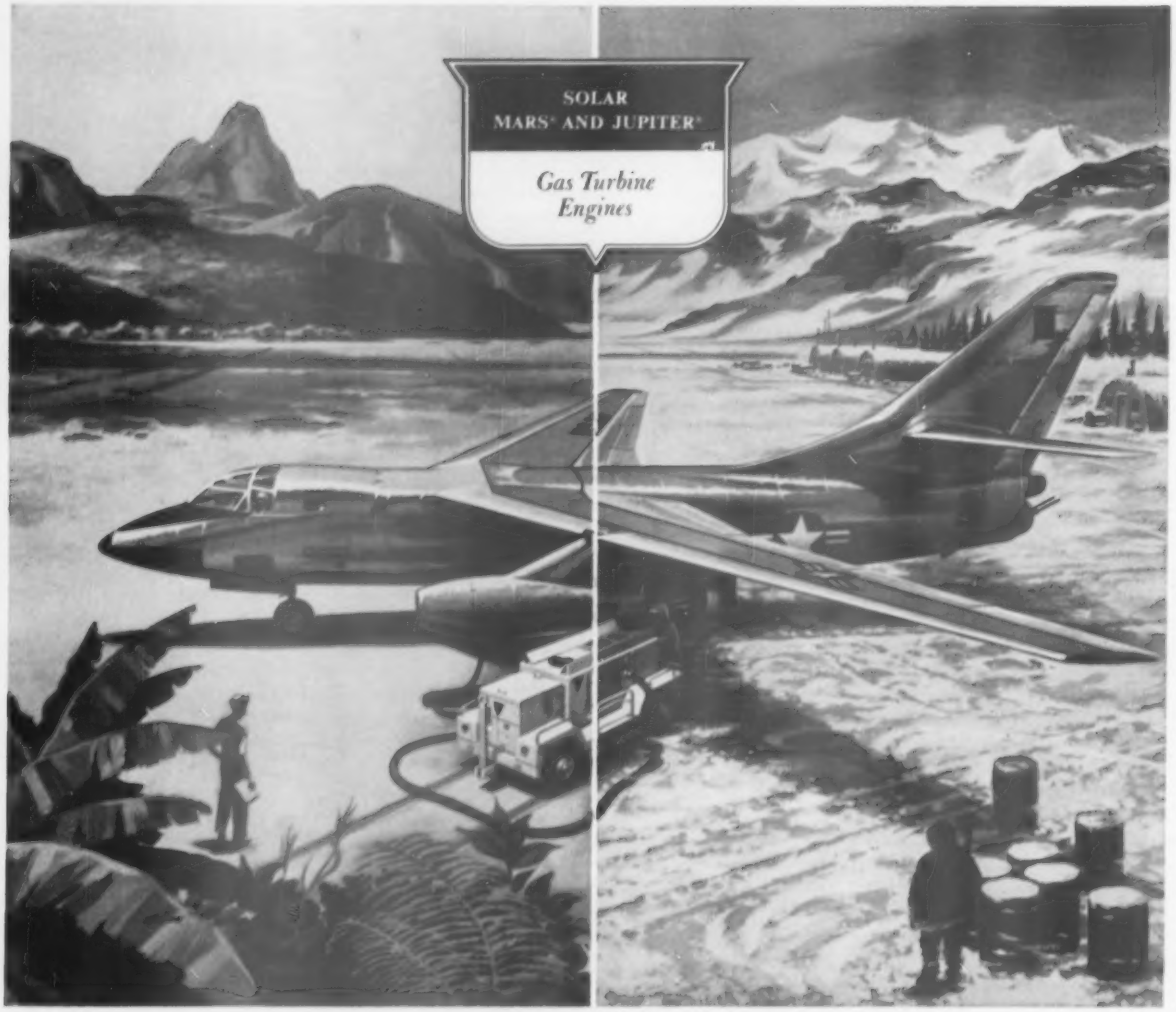

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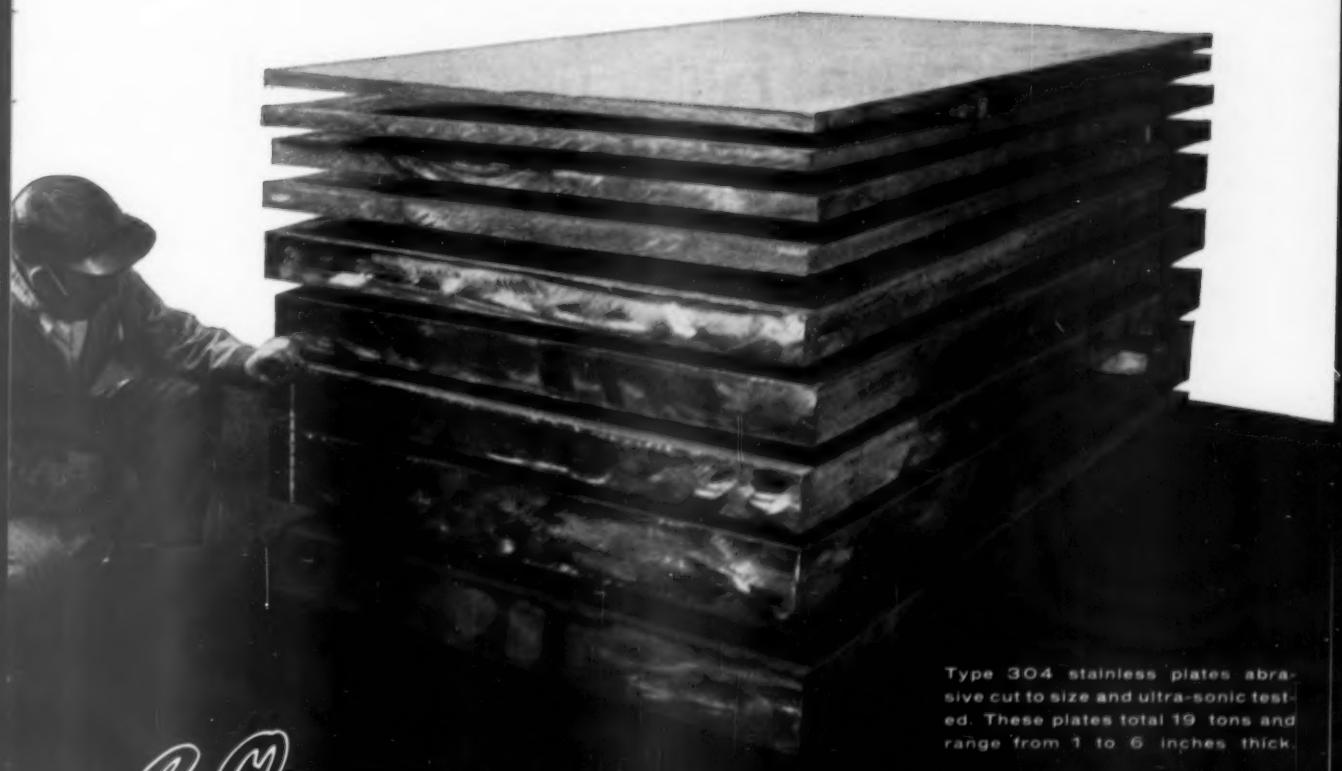

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Green Light For A-Ship

The way is clear at long last for building the nation's first nuclear-powered merchant ship. President Eisenhower, on July 30, signed the authorizing act passed by Congress—now it is up to the Atomic Energy Commission and the Maritime Administration to execute it. Not determined immediately was whether the vessel will be a passenger ship, a dry-cargo freighter or a tanker: Congress recommended a combination passenger-freight ship (*see p. R9*). No limit is set on the ship's cost, estimated at about $40-million.

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Landmark For A-Plane

"In January a turbojet engine was for the first time powered exclusively by heat from an experimental reactor operating on the ground at our testing station in Idaho," AEC Chairman Lewis L. Strauss told the House Appropriations Committee (*see p. 74*). "More ambitious tests will follow. To improve the prospects for early success, a number of independent approaches are being followed in developing a practical design."

•

Gore Bill Aftermath

In a denouement that surprised experienced Washington observers, the controversial Gore bill to accelerate the civilian reactor program went down to defeat in the House four days before Congress adjourned, by the slender margin of a 203–191 vote. Although it had been passed by the Senate, the bill is dead and further legislation on the subject must start from scratch when the new Congress convenes in January. There is some talk in Washington that a package bill may then be offered, combining with the reactor development acceleration two other measures that failed to go through Congress in the closing days of the session: the Federal indemnity program, and exemption from utility regulation for companies during the research and development period of a nuclear power plant project.

The story of the last day of the Holifield bill (identical House version of the Gore bill) is simply that the Republicans were able to muster their forces on the House floor, the Democrats were not. Before the final vote, a long series of amendments watering down the bill—some of them offered by Rep. Sterling Cole (Rep., N. Y.) in an effort to make the bill palatable to the AEC—were carried by heavy GOP margins. On the final vote, the Democrats lost 27 votes to the bill's foes (18 of them from six coal states) while 17 Republicans crossed party lines to vote for the bill; 27 other Democrats and 11 Republicans were paired, or not voting.

The eyes of all who want to see new impetus given to the reactor program are now on AEC, waiting to see whether it will move in the direction of meeting the pressure for a more vigorous program to achieve economic nuclear power, or whether it will interpret defeat of the Gore bill as a Congressional finding that the present speed of its development program is the correct one. (One of the principal reasons AEC gave for its opposition to the Gore bill was that it already had all the authority it needed, and was doing enough, to advance reactor development.) When NUCLEONICS addressed a direct query on this point to Strauss, a spokesman for the AEC chairman replied that no statement was forthcoming at this time; that the Commission has reactor progress under continuous review, "getting reports all the time on new types" and considering whether they merit building of a pilot plant; and that no Commission action had been taken on any counter-program to the Gore-Holifield bill. He added that AEC decisions in this field normally depend in part on industry response—on what projects industry is prepared to pick up; also, that AEC action on new reactor programs now might be premature, with five of the seven "second-round" power demonstration proposals still pending before it.

The tenor of this reply appeared to dampen somewhat earlier speculation that

AEC was indeed preparing an acceleration program of its own. This speculation had been inspired when it was learned that the week before the House took up the Gore-Holifield bill, Strauss had summoned ten leading reactor experts to Washington for a conference to review the AEC reactor program and advise whether "there are other areas in reactor design or concept which are not now being pursued at all or are being pursued with insufficient vigor at this time." If such were held to be the case, Strauss said at that time, he was "confident that the Commission will act expeditiously without impairment of our present reactor or weapons program. If funds from private industry or public power bodies are not forthcoming, in whole or in part, after reasonable time for invitation and negotiation, I will . . . then recommend that the Commission resort to the use of public funds to the extent necessary." Those invited to the conference with Strauss, general manager Kenneth Fields and AEC reactor chief Kenneth Davis, were: Walter H. Zinn, former head, and Norman Hilberry, acting head of Argonne lab; Alvin M. Weinberg, head of Oak Ridge lab; Clark Williams of Brookhaven lab; Darol K. Froman of Los Alamos lab; Eugene P. Wigner of Princeton; Harvey Brooks of Harvard; Hood Worthington of du Pont; Clark Center of Union Carbide Nuclear Co., and Alden B. Greninger of Hanford.

•

Storm & Strife

Meanwhile the political pot was kept boiling furiously during the last fortnight that Congress was in session. Among the issues that erupted were these:

Chairman Clarence Cannon of the House Appropriations Committee, in recommending favorably the expenditure of $400,000,000 under the Gore-Holifield bill (prior to its defeat), issued a report containing a thorough excoriation of Strauss and his policies. Cannon charged Strauss with getting the nation "bogged down in inexcusable stagnation" by his "dogmatic attitude," and engaging in a "deliberate distortion of known facts . . . in a zeal to continue a bogged-down program"; with "vitiating" Congress' intent to keep AEC out of politics; with willfully deceiving Congress and with writing a "duplicitous, false and fraudulent" letter to the Joint Committee on Atomic Energy. So blistering was the 25-page report that Cannon's colleagues forced him to substitute a toned-down version. Strauss also ran afoul of JCAE chairman Clinton P. Anderson who accused him of a "studied insult to Congress" with his "clean bomb" statement.

Safety of the Detroit fast breeder became an issue. Commissioner Thomas Murray, Senator Anderson, and Governor Williams of Michigan demanded publication of a letter by the Advisory Committee on Reactor Safeguards which sets forth its belief that "there is insufficient information available at this time to give assurance that the PRDC [Power Reactor Development Co., the Detroit reactor construction syndicate] reactor can be operated at this site without public hazard" unless a small-scale prototype plant is built first. AEC General manager Fields replied that this was an internal matter still under review. A PRDC official added that the safeguards committee had simply made a routine request for additional design and experimental information without "pointing their finger at any parts of the reactor they felt might be dangerous"; he also pointed out that Con Ed and Commonwealth had been in similar negotiations with the safeguards group for a year before they got their construction permits, and "we've only been at it for six months." Commissioner Murray, however, said he was "as sure as I am sitting here that you will not get the Detroit reactor in operation by 1960." Meanwhile a ground-breaking ceremony was set for Aug. 8.

Walker Cisler became a target too, when Senator Anderson asked AEC to look into the propriety of having Cisler, president of Detroit Edison and PRDC, serve as chief power consultant to the International Cooperation Administration and U. S. delegate to the recent OEEC atomic energy talks in Paris. Anderson said there might be a conflict of interest situation. Cisler serves without pay.

•

13 Bilaterals Pass Test

As Congress adjourned July 27, 13 of 17 bilaterals before it (NU, July '56, p. R1) had completed the required 30-day wait, including the new Australian, Dutch and Swiss power pacts. Only the amendments to bilaterals with Belgium, Denmark, Germany and Sweden must await the next Congress for validation.

Twentieth Semiannual Report Reveals New Projects; Mixed Uranium-Plutonium Fueled Reactor for Hanford

Although AEC seldom uses its semiannual report to Congress as a vehicle for major revelations, the twentieth report covering the first six months of 1956 contained an unusual amount of new information. New projects disclosed included these:

Ninth reactor concept. In addition to the five familiar approaches of the 5-year program (pressurized water, boiling water, sodium-graphite, aqueous homogeneous, fast breeder) and the three added since then (liquid-metal-fueled, organic-moderated, and closed-cycle gas-cooled), AEC has espoused a research and development program on reactors operating on a mixture of uranium and plutonium. General Electric's Hanford Works has been asked to prepare an outline of such a program. Construction of a small experimental reactor is planned as the focal point of the program, using the experience gained on the Hanford production reactors. Combining plutonium with natural uranium as a fuel would, AEC commented, be of particular value to most foreign countries by freeing them from dependence on importing U^{235}. Some domestic reactor designs also included Pu as fuel, although very little r-&-d work on its use has been done. A practical, low-cost Pu fuel element is needed, as well as basic data for design of reactors using both U and Pu, AEC says. Development of U fuel elements will be another objective of this program.

S3G. The West Milton, N. Y., reactor is getting a kid brother: grading has been completed and test-site facility construction begun alongside the huge sphere containing the *Seawolf* prototype for a land prototype of the Submarine Advanced Reactor. This type (formerly SAR, now redesignated S3G) will be used in the first twin-reactor submarine.

NROE. Knolls Atomic Power Laboratory has been assigned the design of a naval reactor organic experiment, in connection with a Department of Defense requirement for a nuclear powerplant of small size and weight suitable for light naval vessels. The experiment is expected to provide information on specific engineering problems involved in the use of organic compounds as a coolant for naval reactors.

Barge reactor. The Navy Bureau of Yards and Docks is doing design studies on a "barge-mounted nuclear powerplant" through the Naval Research Laboratory and the shipbuilding division of Bethlehem Steel.

Nuclear gasification of coal. Initial non-nuclear tests to determine the feasibility of using nuclear heat to produce gas from coal were begun at the Appalachian Experiment Station, Morgantown, W. Va., of the Bureau of Mines. BuMines is building two experimental units, heated electrically, as models of possible future nuclear units; the first is being used in current tests, the second is to be completed soon. AEC, for its part of the joint effort, has initiated a preliminary engineering study to determine the feasibility of a process heat reactor operating in a temperature range around 1,370° C.

Pyroprocessing. Argonne and Ames laboratories and Atomics International are working on various methods of high-temperature chemical separation for fuel element reprocessing. Argonne is concentrating on a process for EBR-2; Ames, on molten metal extraction; AI, on another molten metal extraction system, on direct distillation of Pu and fission products from irradiated uranium, on solid scavenging techniques and on fused salt extraction. Argonne is also investigating the processing of waste materials in fluidized beds.

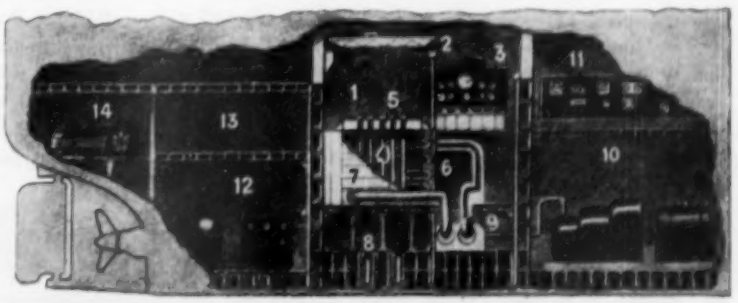
Kinetics of metal ignition. Argonne has begun a study of the pyrophoric behavior of nuclear metals (U, Pu, Th, Zr) by studying factors affecting the kinetics of ignition. This study is designated to make it possible to prevent such incidents as the recent Zr explosion at Oak Ridge (NU, June '56, p. 24) and Th explosion at Sylvania in New York (NU, July '56, p. R12).

It is also disclosed that additional research bilaterals (*see p. R1*) are under negotiation with Ceylon, Ecuador, Guatemala, Haiti, Union of South Africa and Yugoslavia; that discussions on power bilaterals are continuing with Brazil, India, Italy and Norway; that Greece has submitted specifications to U. S. firms and asked bids on a 200–300-kw pool reactor; and Israel has asked bids on designing and constructing a 10-Mw natural uranium D_2O reactor and a pool-type.

Progress on Existing Projects

EBWR. Fabrication of the containment shell completed, pressure vessel installed, power expected to be produced early in 1957.

Gas-cooled. Study contracts with Ford Instrument Co. and Studebaker-Packard Corp. to delineate r-&-d work still to be done, and improve understanding of system economics. Army Reactors branch designing another gas-cooled experiment; Battelle doing materials testing; preliminary design of gas-cooled



MACHINERY COMPARTMENTS OF RUSSIA'S NUCLEAR ICEBREAKER are shown on this sketch received by way of Vienna. Although keys to numbers are lacking, they can be presumed to identify: 1. fuel-changing chamber; 2. crane; 3. reactor control board; 4. reactor; 5. fuel loading ports; 6. primary inlet, outlet ducts; 7. reactor shielding; 8. apparently storage block for spent fuel elements; 9. heat exchanger; 10. turbo-generator; 11. turbo-generator control panel; 12. propulsion motor; 13. empty chamber, possibly for storing replacement fuel elements; 14. steering gear. Items 2 and 8 make it appear that Russians are designing their ship to be able to refuel at sea; although this is contrary to American concepts, by which nuclear-propelled vessels return to port for refueling, it may have been dictated by possibility that an icebreaker for Arctic service might be ice-bound over a winter

ROUNDUP

test loops indicated; contractor being selected to design, build and operate gas-cooled reactor experiment.

STR. The veteran STR Mark I plant at the Idaho testing station, now S1W, has been redesignated again as Naval Reactor Test Facility, is being gradually modified to convert it from a land prototype for the *Nautilus* to a flexible testing facility for investigation of new developments in technology, design, and operation of naval reactors and testing of improved cores. It was refueled for first time after 30 months of operation and testing.

ETR. Construction proceeding on top priority basis; completion and initial operation scheduled for March 1957.

FIR. Conceptual design studies made of several reactor types optimized for gamma production, to select best system for Food Irradiation Reactor; bids asked.

SRE. Delay on some phases set back completion from April to October this year. Southern Cal Edison installing turbogenerator, switchgear, transformers, cooling tower. Four causes of delay: use of wrong type of welding rod on tank, other reactor components, necessitated rewelding or replacement of items; small cracks in end-plates of Zr cans cladding graphite moderator required making new cans, re-cladding; air-blast heat exchanger delayed by fabrication difficulties, other items by a strike.

EBR-1. It is now disclosed that during the power surge of last Nov. 29, temperature in the reactor rose above the melting point of uranium, 1,130° C; this had not been known during the experiment because three thermocouples measuring core temperatures were not operating properly.

KEWB. Atomics International's Kinetic Experiment on Water Boilers facility (NU, March '56, p. 46) is nearing completion.

Washington Report

Insofar as help for the private nuclear industry is concerned, the 84th Congress was rather a "do-nothing" session.

At one point, not too long back, the 84th gave signs of being the industry's best friend. But when July ended and the congressmen went home, the sweet-sounding promises of May and June turned out to be promises and little more.

Indeed, not until the very final hours of the session did the Congress even appropriate the money necessary—$1.9-billion—to operate the Atomic Energy Commission this fiscal year.

The House spoke with negative finality on a Democratic-sponsored proposal to have the Federal Government build and operate a series of small and large reactors for generation of electric power. In a display of partisan unanimity, House Republicans ganged up on the measure after the Senate has passed it. Result: a 203–191 defeat for the bill.

In retrospect, his turned out to be the most crucial legislative action of the 84th insofar as the nucleonics industry goes. The defeat so piqued the Democratic leadership that it did not even call up two crucial measures: Federal liability insurance for nuclear projects, and amendment of the Holding Company Act to exempt power companies participating jointly in noncommercial nuclear projects.

Rep. W. Sterling Cole (R.-N. Y.), a former chairman of the Joint Committee on Atomic Energy, spent most of the final day of the session vainly attempting legislative legerdemain to save the measures. So far as is known, there was no substantial opposition to either, in principle. Certainly this was true of the insurance legislation.

Thus the 84th ended by putting over for another year all of the live issues it faced in this field. In the interval, of course, the nation will go through an election campaign. This is the overriding practical fact to be considered in trying to explain this session's performance.

The man on the spot is AEC chairman Lewis L. Strauss. The dismal sequence that marked the end of the 84th session gives evidence of this. Chairman Clarence Cannon of the House Appropriations committee infuriated Republicans with a report that lambasted the Administration for allegedly allowing the U. S. to fall badly behind both Russia and Britain in nuclear power development for peaceful purposes. Cannon put the U. S. lag at three years—and "these three years coincide with the reentry of Mr. Strauss into a position of dominating influence in the atomic energy field."

Strauss, as the Administration's chief spokesman in this field, wanted the insurance and holding company legislation and was opposed to the Gore bill. All the issues will be revived next year. And looking ahead to 1957 and the 85th Congress, it seems logical to put chances for the insurance legislation in the excellent column—no matter which party is in control. Senator Gore has already given notice that he intends to reintroduce his bill on the first day of the new session, and if the Democrats retain control of Congress, there will be a serious attempt made again to pass the Gore program of AEC-built and -operated reactors. However, if Republicans organize one or both houses, its chances will become almost nil. The amendment to the Holding Company Act will have more chance of final passage in a Republican-dominated Congress.

But between now and then, the nation will be treated to a political debate on what is wrong—if anything—with the U. S. nuclear program.

2d Annual AEA Report Out; Development Speeding Up

Some new insights into the direction that the British nuclear energy program is taking can be gleaned from the second annual report of the U. K. Atomic Energy Authority, just released, covering the year ending March 1956.

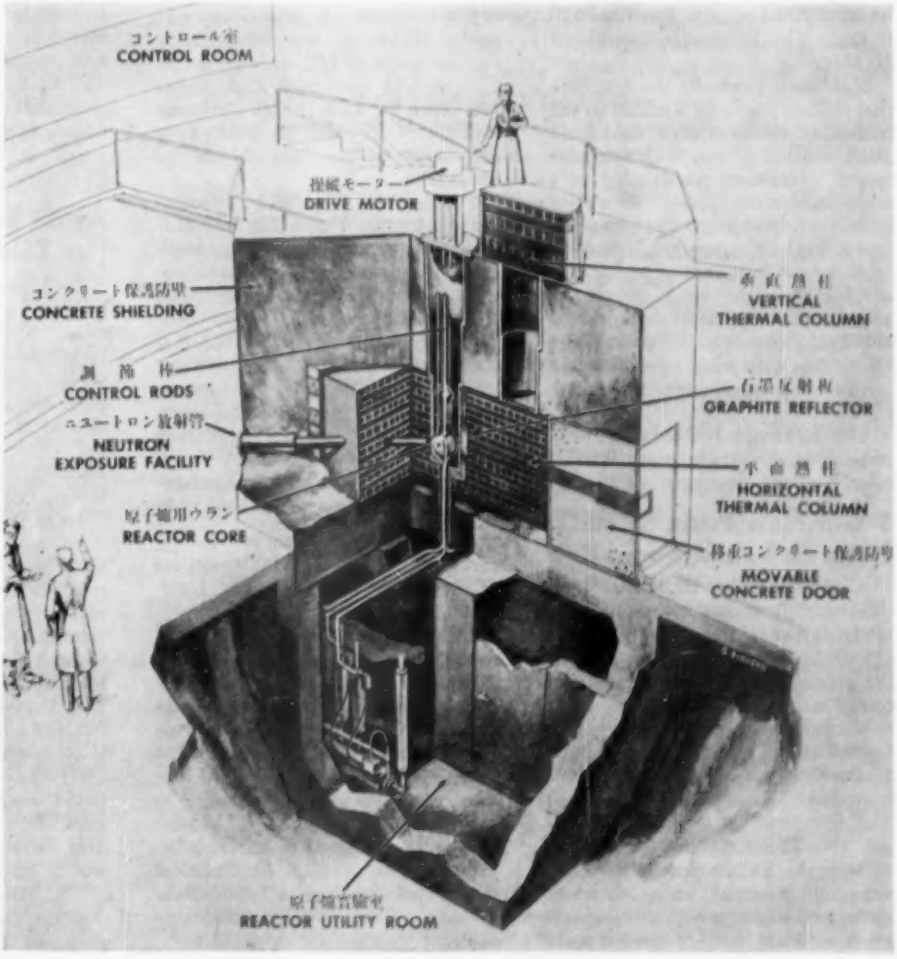
The report asserts that doubling of the output of Calder Hall-type stations for the first few Central Electricity Authority power plants is a conservative estimate. Neither AEA chairman Sir Edwin Plowden nor AEA research chief Sir John Cockcroft would offer firm technical reasons for the boosted heat ratings, saying that this is not possible until the industrial groups' bids are received within two months' time. Indications are that the main factors will be that thicker reactor plate and other structural refinements will make possible higher CO_2 pressures.

The giveaway is the fact that the independent South of Scotland Electricity Board has announced plans to build a 250–300-Mw station using two Calder Hall-type reactors. This represents a 250% uprating.

In listing test loops available in British research reactors, the report describes the nature of research for assessing both pressurized-water-cooled and sodium-graphite reactors competing for the Phase-2 stations in the power program. For the first time, the Authority admits that the sodium graphite system now looks to be the choice (NU, May '56, p. 19).

Among other disclosures made in the reactor field were these:

- Problems associated with increased size and vertical alignment of reactor cartridges, such as at Calder Hall, have been overcome by the use of new equipment. Also, periscopes and television cameras have proved of inestimable worth in monitoring mechanical integrity of the pile and structure. This, in conjunction with specially-developed remotely-operated tools, makes possible lining repairs and the use of short-lived expendable components. The tools range from hammers to welding equipment. These facilities ease the severe design limitations; formerly the life of the pile was limited to that of its components.
- The complete separation of U^{233}, fertile thorium, and the fission products from neutron-irradiated thorium has been achieved in a pilot plant and confirms plant flowsheets.
- A switch has been made from calcium to magnesium in the reduction of uranium tetrafluoride and continuous-flow processing has been adopted. A plant nearly completed will eliminate worker contact with metal. The switch leads to great cost reductions.



WATER BOILER FOR JAPAN is shown on drawing prepared by Atomics International for its client, Japanese AEC, complete with translated captions. Final design has been completed, fabrication begun, and instruments, parts and materials are being procured. Enriched uranyl sulphate reactor is similar to one AI recently completed for Armour Research Foundation in Chicago, but has unique design to prevent discharge of any radioactive gases or other fission products into atmosphere. Gases will be retained inside primary where they are circulated and recombined. This has added advantage of providing a source of neutron-free gamma rays for medical and scientific research. Japanese plan to use reactor, their first, in several fields including medical research; drug sterilization; food preservation; production of radioisotopes; effect of radiation on plastics, rubber, and similar materials; and research in botany, biology, and agriculture—as well as for research in reactor techniques. To be located near Tokyo, it is to be completed in early 1957

ROUNDUP

• Hydrodynamic-type bearings using gas coolant as lubricant are now being used.

The general tone of the report indicates that the development is continuing without startling highlights, although at an increased rate. The growing momentum of the research effort is reflected in the 30% increase in scientific personnel during the last year; the total number of AEA emloyees now stands at 24,000. [By comparison, the USAEC employees only 6,050, but in addition there are 107,000 AEC-contractor employees working on AEC projects.]

Britain plans to build a huge proton synchrocyclotron, leapfrogging present Russian and U. S. projects. A 6–7 Bev machine, it will have a flux 100 times that of the one now the world's largest, recently commissioned in the USSR. Design studies have been completed. New focusing methods will make possible a much smaller magnet weighing under 5,000 tons and less than 120 ft dia. The injector is capable of 10 Mev.

Mention is made for the first time that Britain has been working in the controlled thermonuclear field since 1948, achieving "very high temperatures." Persistent questioning at a press conference failed to obtain from Sir Edwin what was meant by "very high temperature," nor to what extent Britain is now engaged in thermonuclear work. Both he and Sir John appeared embarrassed and finally conceded, "We are doing all we can with what scientific manpower and equipment are available."

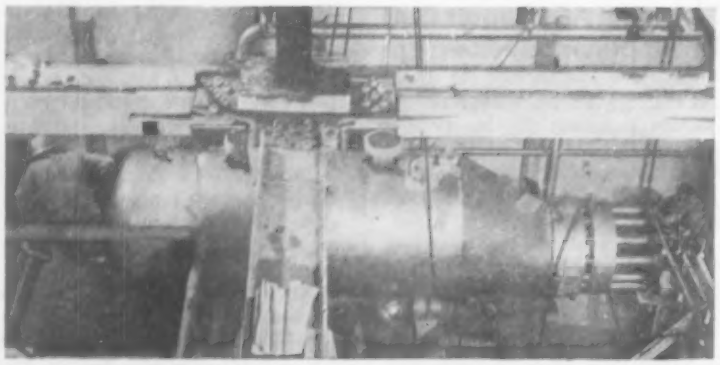
The inference that neither were commensurate with the Russian effort was undeniable.

5 Get New Posts as AEC Expands International Unit

AEC reorganized its staff to keep pace with growing activity in the international field.

Paul F. Foster, special assistant to the general manager for liaison, becomes assistant general manager for international activities, and is succeeded in his former post by John L. McGruder. Foster will be responsible for coordination of all AEC international programs, including the bilateral and multilateral agreements for cooperation in developing peaceful uses; disarmament; and contacts with the Department of State, foreign governments and the U. N. John Hall continues as director of the division of International Affairs, under Foster.

Edward R. Gardner, deputy director of the international affairs division, became head of a new office of Special Projects, having responsibility for disarmament activities and for special projects that may arise in the international nuclear program. He is succeeded in his old post by Allen J. Vander Weyden. Raymond R. Edwards became assistant director for technical support of the international affairs division. Clark Vogel continues as assistant director for operations.



HRE-2'S HEAT EXCHANGER being lowered into position at Oak Ridge. This is exchanger on blanket side; an identical one is on fuel side. Blanket liquid enters and leaves at right end, feed water enters at left, two steam outlets are on top. Overall length is about 14 ft, outside diameter of steam drum 40 in. Total heat transfer area is about 500 ft²; 1.62 × 10⁴ lb/hr of steam is produced at 520 lb/in.² and 244° C

Oak Ridge Marks 10 Years of Isotope Shipments

Just ten years ago, on Aug. 2, 1946, the first shipment of radioactive isotopes to a general user was made. It was a package containing one millicurie of C^{14}, made in the X-10 graphite reactor at Oak Ridge and sent by Oak Ridge National Laboratory to the Bernard Free Skin and Cancer Hospital in St. Louis, Mo.

This month ORNL and its operating contractor, Union Carbide Nuclear Co., are celebrating the tenth anniversary of radioisotope shipments for civilian uses. Since then, the radioisotope distribution program has come of age: in the first eleven months of 1955, 12,678 shipments were made to U. S. addresses and 719 more to 50 foreign countries. Almost 3,000 domestic users —medical institutes and physicians, industrial firms, colleges and universities, foundations, federal and state laboratories—have benefited from 85,128 shipments during the ten years of the program's existence.

As has been pointed out at ORNL, radioisotope production is not only a new industry but a completely new type of industry: one in which total annual production of a product distributed in 12,000 shipments altogether weighs barely 0.0001 ounce, in which the packaging must weigh one billion times as much as its contents.

Await Reactor Experience, Fox Told Japanese AEC

On his recent visit to Japan at the head of an American nuclear survey team, Marvin Fox, chairman of Brookhaven National Laboratory's reactor department, was asked by Japanese AEC chairman Matsutaro Shoriki to discuss and comment on the U. S. power reactor program vis-à-vis the British program. Just before, Sir Christopher Hinton had been in Tokyo where he pressed the advantages of the gas-cooled Calder Hall type reactor, in terms of no restrictions on the natural-uranium fuel supply and in terms of power generating costs of 10 mills/kwh without Pu credits. It was on the basis of this information that Shoriki took the position that Britain was "well ahead of the U. S." in the race to achieve competitive nuclear power (NU, July '56, p. R5), and that Japan would turn to the U. K. for most of its nuclear power aid in the near future unless the U. S. could match British claims.

The Brookhaven team took the position that no country was really prepared to make such optimistic

claims on generating costs until experience demonstrated some validity, and that there is little to distinguish between the U. K. and the U. S. policies with respect to uranium fuel supplies. Speaking for himself, Fox said that he felt the present restrictions on fuel were makeshift, fluid, and such that it would be a mistake to base a longrange power-reactor program on the situation as it exists today.

The recommendation offered to Shoriki by the Brookhaven team, Fox told NUCLEONICS, was that Japan could satisfy its immediate energy needs by buying power reactors as they are offered for sale today, either in the U. K. or U. S.; but that decisions on a long-range program of nuclear-power development should wait for a few years until some operating experience has been gained. Thus Japan could take advantage of the large and costly programs underway in the U. S. and the U. K.

Fox says the Japanese promised to send a survey team to the U. S. later this year to look at American reactor designs, in addition to the team they are sending to Britain.

Zinn Forms New Company For Consulting Services

Walter H. Zinn, director of Argonne National Laboratory from its establishment until a month ago, has formed a consulting firm—General Nuclear Engineering Corp.—with headquarters in St. Petersburg, Fla., and thereby satisfied industry-wide curiosity as to his next affiliation. Joining him in the new firm, of which he will be president, are three key Argonne associates. They are Harold V. Lichtenberger, until now in charge of Argonne operations at the Idaho reactor testing station; John M. West, in charge of the EBWR design and construction group; and Joseph R. Dietrich, responsible for the theoretical physics work on the *Nautilus* prototype and on boiling reactor development. The four men have a combined total of 54 years of experience in the nuclear field.

Zinn said that the company, formed for the purpose of providing "engineering and other services" in connection with the design, construction and operation of reactors and other nuclear facilities, is equipped to undertake design of nuclear power plants, research reactors and special-purpose reactors. Experience of the group encompasses sodium-cooled reactors, graphite-moderated reactors, heavy-water-moderated re-

About the Industry

Westinghouse expands at Large. A renovation of facilities in support of its Bettis activities at Large, just south of Pittsburgh, will give Westinghouse 120,000 ft² of new space for engineering labs, test facilities, and machine shops. The main site at Bettis will concentrate on research and development of nuclear power plants, Large will consolidate application, engineering, and test groups. The Large site, which housed 15 people at startup in October 1951, now employs 1,000, and will have 2,000 when renovation is completed at year's end.

Opportunities for industry. Still another of AEC's many recent appeals to private industry to take part in the nucleonics business* was made by Charles G. Manly, chief of policy and programs in AEC's division of civilian application. He said AEC is looking for an industrial firm interested in:

1. reprocessing cold uranium fuel scrap, now going to waste;
2. disposing of hot waste products from reactors;
3. reprocessing spent reactor fuel elements;
4. manufacturing uranium metal from U concentrates.

Declaring he was puzzled at industry's disinterest in getting into the nucleonics business, Manly observed, "There seems to be a common misunderstanding in the industry to the effect that you cannot get into the atomic energy business unless and until the AEC puts out a special invitation. Nothing could be further from the truth. Opportunities to get into this business are all around you—all you have to do is seize them. What you have to do is provide the initiative and find a niche for yourself."

The business of reprocessing cold—i.e., non-radioactive—uranium scrap would require a capital investment of about $500,000.

Radiation effects on electronic parts studied. Admiral Corp. has undertaken for the Air Force a three-year investigation of radiation effects on electronic components in planes and ships, said to be the first carried out by private industry. Admiral has designed and built for the project a special laboratory in Chicago, to which components "cooked" in reactors at Argonne or the Idaho reactor testing station will be brought for examination.

Radioactivity symposium. Tracerlab Inc. has scheduled the third in a series of symposia on industrial applications of radioactivity for Oct. 24–26 in Boston. It will deal primarily with furthering the development of isotopic techniques in research and refinery operations of the petroleum industry, one of the first and now one of the largest users of isotopes.

Crane organizes unit. The Crane Company, maker of valves and fittings and a supplier for both military and civilian nuclear energy programs since Manhattan District days, is the latest to set up a separate nuclear energy unit. A part of Crane's engineering sales section, it is to be headed by Fred G. Gould and will service all inquiries and orders for Crane equipment in the nucleonics field. Crane has supplied most of the valves for *Nautilus*, has designed a series of giant valves for the Shippingport PWR, and has orders for valves and fittings for LSR, the land-based surface ship prototype now under construction at the Idaho reactor testing station.

* NU, Dec. '55, p. 13, uranium salts; Jan. '56, p. 16, beryllium; Feb., p. 13, chemical reprocessing; p. 16, fluoride scrap; April, p. 18, yttrium; p. 19, chemical industry; p. 21B, uraniferous lignite processing; June, p. 21B, uranium concentrates, feed materials plant capacity.

actors, and light-water-moderated and -cooled reactors.

Recognizing the shortage of trained personnel in the field, Zinn said it was his plan to engage scientific and engineering talent locally insofar as possible and to provide on-the-job training, thus adding to the country's reservoir of trained personnel.

Congress Sees Manpower Lack 'Biggest Deterrent'

A public hearing into the shortage of scientific and engineering manpower, held by the Price subcommittee of the Joint Committee on Atomic Energy, concluded that this shortage is "the greatest single deterrent to progress in our atomic energy program."

After six days of hearings, 32 witnesses and nearly 500 pages of testimony, the research and development subcommittee came up with ten major recommendations, one of which is in the nuclear field, the other nine applying to educational programs in general.

Because the estimated need for reactor technicians is 2,000 for each of the next two years whereas we are at present producing only 500 per year, the committee recommended that all possible steps be taken to increase the number of such technicians, including: expansion of the government's reactor training programs; increasing the number of "reactor kits" containing sub-critical assemblies to be made available to universities for instruction in reactor technology; and providing aid and assistance to universities in the construction and operation of research reactors.

Senators Hit Exchange of Military Data with UK

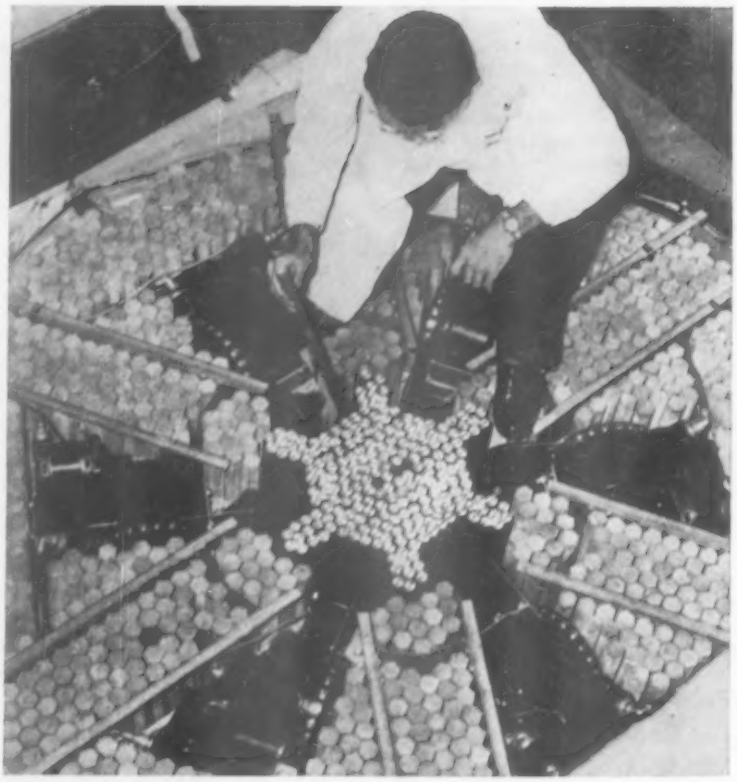
Amendment of the US-UK bilateral to permit giving the British secret data on our nuclear submarines and nuclear airplane development work was criticized by Senators Clinton Anderson and Albert Gore of the Joint Committee on Atomic Energy. They scored both the agreement and the manner in which it was made, allegedly circumventing Congress.

Soviet Union Has 200 Cobalt^{60} Sources

Curiosity about Soviet work in radiation teletherapy was satisfied in part last month when it was revealed that the USSR has 200 cobalt-60 sources in use having an average radioactivity of 400 curies each. This compares with the U. S. average source strength of 1,000 curies.

At the Mexico City International Congress of Radiology, V. A. Petrov, chief of the physical laboratory of the Leningrad Roentgeno-Radiological Institute, gave a paper on "Physical Aspects of Gamma Therapy with the Use of Sources of High Intensity." In discussion following his paper, Petrov cited the number of sources in use and also gave a surprisingly high figure for the specific activity that the Soviets have been able to achieve with a Co-60 —60–70 curies/gm. In the U. S., 30–50 curies/gm is considered the highest maximum practical from the economic point of view, although experimentally 180 curies/gm has been achieved.

At the meeting, it was also revealed—by Paul Aebersold, chief of AEC's Isotopes Extension—that AEC will be turning out 200,000 curies per year of cesium-137.



CORE-LOADING OF ZEUS, Britain's Zero Energy Uranium System, the critical assembly for fast breeder being built at Dounreay (NU, May '56, p. 19). A Harwell scientist adds a plutonium central core rod; surrounding them are blanket rods of natural uranium

AEC Sets New Criteria For Access to Fusion Info

AEC announced new criteria for getting access to data on controlled thermonuclear reactions—an access category that had been announced and then withdrawn pending review (NU, June '56, p. 20B). The new rules require an applicant either to be "engaged in a substantial effort to develop, design, build or operate a fission power reactor that is planned for construction," or "possess qualifications demonstrating that he is capable of making a significant contribution" to thermonuclear research. This is designed, AEC said, to limit fusion access to those who can "give evidence they are expending significant funds or effort on a specific fission power project planned or in being, so they will have opportunity to evaluate the potential of controlled thermonuclear processes," and to those who can contribute to thermonuclear development.

Reactor News

Critical assembly for Denmark. Atomics International has announced sale of a five-watt homogeneous reactor for the Danish nuclear research center now building near Roskilde, 20 mi W of Copenhagen. The critical assembly, of the water-boiler type, will use enriched uranyl sulphate solution for fuel and is to be completed and in operation by next spring. It will be used by the Danish AEC in conjunction with a 5-Mw tank-type research reactor which it ordered a month ago from Foster Wheeler, and which is to be completed in about one year. The U. S. is contributing $350,000 toward the latter's $1.4-million cost.

Heat exchange work in Russia. At the recent World Power Conference in Vienna, M. A. Styrikovitch of the USSR, reporting on "Working Processes of Super-High-Pressure Once-Through Boilers," discussed investigations of steam properties and heat exchange carried out in connection with the development of new reactor types. One of these is a boiling-water reactor producing steam at 180–200 atm; the core is so arranged that steam is produced in some channels and superheated in others. Heat transfer coefficients for this type of reactor were determined under extreme conditions of steam velocity, heat transfer, and through a large temperature range. Another type of reactor planned, using D_2O moderator and CO_2 coolant, heats the gas up to 450° C while the moderator is kept at 75°. This is achieved by surrounding each gas-carrying coolant channel with an annulus in which cold CO_2 flows, later to be merged with the hot CO_2 stream to cause a 10° C temperature drop. Special studies were made of the radioactivity of steam in boiling reactors. Through multistage scrubbing of steam with condensate, it was found possible to reduce carry-over activity by many orders of magnitude.

. . . and a new thermal column. A Soviet delegate at a recent reactor-physics conference in London disclosed use of a new type of thermal column in his country. It is composed of a cluster of uranium oxide rods housed in an annulus formed by concentric beryllium cylinders.

Omega West goes into operation. Los Alamos Scientific Laboratory's 1-Mw MTR-type heterogeneous research reactor began service July 11 (*see p. 51*).

Hardware at Ft. Belvoir. APPR—the Army Package Power Reactor—has taken shape, at least externally, at the Corps of Engineers headquarters in Virginia. The 64-ft high, 36-ft-dia vapor container, whose ¾-in. steel plates when disassembled will fit in an airplane, has been completed, and every inch of weld radiograph-inspected. It is now getting its 3-ft outside coating and 2-ft inside lining of concrete, and on its floor are being readied the foundations for the reactor vessel.

No APPR for Alaska. A proposal for an APPR-2 to be set up in Alaska, to provide both heat and power, failed to get a green light when the House Appropriations committee deferred $36-million funds for it, because testimony showed construction could not begin before 1958. But the committee did allow $500,000 for design work.

Enlargements at MTR. AEC awarded a $116,350 contract for construction of an extension to the Materials Testing Reactor building wing at the National Reactor Testing Station in Idaho. Another improvement in MTR services will be the building of a balcony in the building to provide additional instrumentation and work space around the reactor top.

BNL medical center underway. Construction has begun at Brookhaven on AEC's first medical research center with a reactor. Malan Construction Corp. of New York is building contractor on the $6-million project, which will include a medical reactor to be built by Daystrom (*see p. 50*). The buildings, including the reactor building, are scheduled for completion in late 1957: Malan—which is also building a hydrogen liquifier lab at Brookhaven—has 540 days to finish its job.

Bids due on food reactor. AEC will invite proposals on design, development, and construction of the proposed food-irradiation reactor to be used by Army Quartermaster Corps for research on food preservation (NU, June '56, p. 24).

Mixed passenger-cargo ship type chosen. A Senate-House conference committee reconciled differing versions of a nuclear merchant ship bill, and Congress sent it to the White House for signature. This greases the ways for the long-stalled project, and Sen. Warren G. Magnuson, head of the Senate Commerce committee and a leading merchant marine expert in Congress, predicted "a good atomic merchant ship flying the American flag will be on the high seas" in 18–26 months. The conference committee report—which although not binding, has the force of Congressional recommendation—says the ship should be "a practical merchant vessel of combination passenger and cargo design." The Maritime Administration, which will build the hull to carry the AEC-built reactor, had argued strongly in favor of a tanker as the application in which nuclear power would come closest to being economically competitive at once. The committee report also sought to settle another long-standing disagreement over the reactor type by ruling out a *Nautilus* reactor copy: "It was the contemplation of the conferees that the vessel would contain the most advanced type of reactor possible for a practical merchant ship which would be a definite step forward in the art of nuclear propulsion utilizing all experience and improvements learned to date . . . not one which has already been produced for other purposes." This points to an advanced, specially-designed pressurized-water type.

Another kind of vessel. New York Shipbuilding Corp. of Camden, N. J., builder of seagoing vessels, has received a $2-million contract from General Electric to build what they describe as the largest pressure vessel of its type ever built. The welded steel tank 42 ft high is destined for the boiling-water reactor in Chicago Commonwealth Edison's Dresden nuclear power station. A cylindrical vessel 12 ft 8 in. inside dia, it will stand upright inside the 190-ft dia steel sphere that will be the vapor container for the 180-Mw plant. It will have ¾-in. stainless cladding on the inside of a 5-in. carbon steel welded assembly, will weigh 400 tons, and will hold 278,000 lb water. The control-rod assembly to be installed in the vessel will weigh 40,000 lb; the reactor core will weigh 265,000 lb. It is designed for operating pressure and temperature of 1,000 psia and 545° F, and will be engineered for an operating life of 40 years. New York Ship will also furnish a supply support ring, core nozzles, steam outlets, and control and monitor openings.

Report from Finland

HELSINKI

At the present time there is no research or development in Finland that properly could be described as part of an organized nuclear energy program. A State Committee of experts set up in March 1955 to consider the country's energy requirements—its title, "Contemporary Energy Committee," was chosen to signify that the Finns are not committed to nuclear energy as the sole source of future power—reported in April this year its conclusion that nuclear power is not yet economically or technically competitive with conventional power. It recommended adding hydro capacity permitting an increase in energy production of 800-million kwh/yr for 10 years, by which time essentially all of the practicable water sources will have been utilized. With no native coal or oil, Finland has an obvious incentive to get into the nucleonics business as fast as possible. However the limited manpower—the population is only 4 million—imposes great care about the way this manpower is expended. Accentuating this is the strain placed on Finnish industry by the heavy reparations Russia exacted. As a result, there is a healthy caution and skepticism in Finland about the prospects for nuclear power and a readiness to examine all aspects before taking action that contrasts sharply with the almost unbridled optimism found in some other European countries.

It was, in fact, because of the need for husbanding manpower that the Contemporary Energy Committee was formed. It is not surprising, therefore, that it called attention to the need for trained scientists and technicians in the nuclear field, and recommended that all institutes in Finland capable of training such personnel get State support in their efforts. It also called for establishment of a permanent atomic commission representing the government, scientific, and economic interests, to plan education in nuclear science and help direct Finland's nuclear foreign policy.

Besides the Technical Institute, there are three universities—Helsinki, Turku and Abo; two of the three do good work in physics. At the Technical Institute in Helsinki, there is no work in experimental nuclear physics but some research in the theory of nuclear models. The solid-state program impresses, however, with its emphasis on precise measurements of magnetic properties, specific heat, and conductivity of various materials. It is probably at the Technical Institute that a research reactor would be placed because of the emphasis on both basic and applied physics. At the University of Helsinki, a Van de Graaff under construction for several years has recently begun operation. Voltage regulation of the machine is extremely good, and the research program now beginning seems to be on a level with most of the work in the Van de Graaff field in the U. S. In addition to precise heat measurements similar to those at the Technical Institute, there is first-class work here on the diffuse scattering of X-rays resulting from lattice vibrations, furnishing information on crystal lattice vibrations exactly analogous to that being obtained at Brookhaven by neutron scattering.

Finland's second city, Turku—or Abo as it is called by the nation's 10% who speak Swedish—has two universities: the Swedish university of Abo does not have much work in physics, concentrating more on the humanities; but the University of Turku is expanding extremely rapidly and has built extensive, well-equipped laboratories.

In general, education for scientists seems to be extremely good, but the number of men trained each year is insufficient to support an active nuclear-energy program. This makes it important for Finnish scientists to go abroad for training, so that they may educate more Finns on their return. However, there is reluctance to send men abroad, particularly to the U. S., because of the number of graduate students who have decided not to return to Finland. Reassuringly, the Finns have not been sending men to Russia for such training.

The Finns are interested in the extent to which they would have to "go it alone" in the contemplated nuclear energy program. They want to make it as self-contained as possible, and are wary of U. S. aid, fearing that supply of U^{235} or fuel element reprocessing might be used as a means of controlling the Finnish economy. They would be perfectly willing, on the other hand, to rely on a centralized European facility for such services, if one were set up.

The nuclear-energy program now envisaged by the Contemporary Energy Committee shows no inclination to rush ahead at once with a power reactor. The members seem reluctant to commit themselves to any definite line of development, much less start any actual construction. The Finns would be interested in getting, as soon as possible, a reactor producing low-cost process steam for their tremendous wood-pulp industry. But they have little interest in a high power reactor for electricity in the next few years, feeling that improvements are inevitable and that they would do better to let other countries pioneer them. Contributing again is their fear that if they cannot manage a complete program on their own, they will become subject to the control of one of the large nations on whom they would then depend. It is easy to understand their fears when one realizes that their entire supply of oil today comes from the East and can be cut off at any instant if the Russians so desire.

But American observers feel that too much caution now might hold back the future development of a Finnish nuclear program. Two vital steps that they would urge Finland to take now are construction of one or more research reactors, and the training of key people abroad.

The Finns still maintain their traditional great friendliness toward the West—and their dislike, almost contempt, for the Russians. They have had to develop entire new industries to complete the severe reparations; now that that has been paid, they would much prefer to discontinue trading with the Soviet and to send their products to the West instead.

(This article is based largely on a report to NUCLEONICS by Donald J. Hughes of Brookhaven, who recently made an official visit at Finland's invitation.)

World News

France begins power station. Electricité de France has begun work on EDF-1, France's and western Europe's first nuclear plant for power only. Located on the Loire river SW of Paris, EDF-1 is to be completed in 1959 and produce 60 Mw for the national grid. Work on EDF-2 is slated to start in 18 months. Three Pu-and-power reactors are building at Marcoule (NU, April '56, p. 22).

Neutrals discuss nuclear action. Five Oriental "third force" or neutralist powers—Egypt, India, Ceylon, Burma, and Indonesia—held two days of talks in Bombay to discuss possibilities of close cooperation in nuclear development for peaceful purposes.

Nuclear power for East Germany. In Soviet-East German talks in Moscow last month, it was agreed to set up a 100-Mw nuclear power station in Red Germany. "The Soviet Union," according to a joint communique, "will render aid by preparing the blueprints of the station and supplying the German Democratic Republic with the necessary equipment and material."

First British power sites approved. The Central Electricity Authority has received consent from the Ministry of Fuel and Power to locate its first two nuclear power stations at Bradwell and Berkeley (NU, Dec. '55, p. 14; Feb. '56, p. 15; map July p. R8). Local inquiries had been held on the CEA's site applications. Each station will have two Calder Hall type CO_2-cooled graphite-moderated reactors, an aggregate electrical output of 200 Mw, and a capital cost of $336 per installed kilowatt. Construction bids are due by Oct. 1 from British private industry groups and awards are to be made by year's end; site preparation and access roads are being started at once.

Germany making fuel elements. Degussa, the German company whose name consists of the initials for "German Gold and Silver Separating Establishment" but whose manifold activities today include preparation of high-purity uranium, will fabricate several types of fuel elements for test purposes for the German research reactor to be built at Karlsruhe.

Venezuela in market. Babcock & Wilcox is one of a number of companies that have been asked to bid on a medical reactor for the Instituto Venezolano de Neurologia e Investigaciones Cerebrales, now building a new neurological research center in the hills above Caracas. The reactor the Institute wants is described as "a closed type of heterogeneous H_2O-moderated and -cooled reactor, operating at 1 Mw with peak power of 3 Mw and a flux from 10^{13} to 10^{14} n/cm²/sec," and using "hot, pure" elements. It would also have an adjacent storage facility for spent fuel elements permitting use of their gamma radiation. The soundness of the Institute's program has impressed a number of USAEC officials.

France buying fuel. France has signed a contract to purchase 88 lb of American U^{235}—70 lb at 20% enrichment, 18 lb at 90%—as well as small amounts of U^{233} and plutonium for experimental projects. The contract gives the U. S. first option on purchase of byproduct Pu produced in French reactors.

Lab in the hole. The British Radiological Service will install a laboratory for investigating the amount of radiation absorbed in the body in a deep hole at Sutton, Surrey. The chalk in which the hole will be dug will keep out natural radiation, and thus facilitate the measurement of Sr^{90} fallout uptake.

Soviet aid to Egypt increases. A second agreement for cooperation in the nuclear field between Egypt and the USSR has been signed in Cairo. Supplementing an earlier pact under which Russia is supplying a 2-Mw research reactor, it provides for exchange of research workers, training of Egyptians in the Soviet, and delivery of a 3-Mev cyclotron as well as other equipment and instruments for the projected Egyptian nuclear research center. This center, to be completed in mid-1958, will be the largest of its kind in the Middle East.

Regional international bodies mooted. A long-discussed regional organization was debated and two new ones proposed last month. In Paris, ministers of the 17 OEEC (Organization for European Economic Cooperation) nations met to discuss plans for cooperation in the nuclear field. A steering committee was set up with representatives of the 17 OEEC members plus the U. S. and Canada as associate members. Special study groups will start work by Sept. 15 on specific problems of joint nuclear undertakings: Belgium, France, Germany, Italy, Luxemburg, Netherlands, Denmark, Sweden, Switzerland, and Turkey are studying problems of a uranium isotope-separation plant; Austria, Britain, Denmark, Norway, Portugal, Switzerland, Sweden, and Turkey are studying fuel reprocessing plants; a third group is looking into heavy-water production. One great advantage of the OEEC plan is that it involves no treaty requiring ratification by parliaments containing local special interests, as does Euratom (the more tightly-knit nuclear pool project of the six coal-steel pool nations). Meanwhile, two new regional groupings were proposed. The Soviet Union called for a conference to establish an all-European regional body, including also the U. S. and USSR, for exchange of information and coordination of development of nuclear resources. But as the Soviet note contained a violent attack on Euratom and West German participation therein (she allegedly would have an opportunity for atomic rearmament), Western diplomats dismissed the move as anti-Euratom propaganda. One week later in Panama, President Eisenhower called for a Western Hemisphere organization to "hasten the beneficial use of nuclear forces, both in industry and in combatting disease."

Reactor for West Berlin. Joining the parade of West German cities lining up for a research reactor, Berlin—according to advices from abroad—placed an order for a 10^{13} n/cm²/sec-flux water-boiler with Atomics International division, North American Aviation. It will be shared by the Technical and the Free University of Berlin. Cost of the reactor and associated buildings will be $1-million; operation will cost $476,000 per year. Together with two new nuclear-energy professorships and purchase in 1958 of a particle accelerator, West Berlin is spending $3-million on nuclear training.

Progress at Lucas Hill? Assembly of Australia's first reactor is about to begin at Lucas Heights, Sydney. Several shipments of components have arrived from Britain and West Germany (NU, Feb. '56, p. 15) and the rest are due by year's end; completion of the Dido-type 10-Mw research reactor is set for next June. So stated a NUCLEONICS dispatch from Melbourne; but on its heels came another: several hundred workers have been dismissed at the project. Shortage of funds and a reevaluation of plans following conclusion of a power bilateral with the U. S. influenced the government to proceed at a slower rate.

ROUNDUP

News in Brief

AEC aid to universities. Details of AEC's expanded program for loan of neutron sources and uranium to universities (NU, July '56, p. R12) have been decided. Five forms of uranium are available without charge: UO_2 powder, UF_4 salt, metal billets 40 in. long × 7 in. dia; and Al-canned slugs either 8.4 in. long × 1.34 in. dia, or 8 in. × 1 in. Other forms and shapes are available at varying costs. Total uranium for any one institution is limited to 2,500 kg, for safety considerations. Also available without charge are Po-Be neutron sources, to a maximum total of 25 curies. Only handling and shipping costs are charged to the university; for a 2,500 kg shipment, this may come to $100 for canned slugs, less for other forms. Security measures to protect the material are not required, as they are unclassified, but material lost will be charged for at $40/kg of billet metal. Additional fabrication on the material is at the borrower's cost. A source or byproduct material license and a standard-form AEC contract will be required, but no facility or operating license. The university must also describe the proposed facility to be built (*cf p. 64*) and have funds available to complete and operate it.

Thyroid study at ORINS. One of the four advanced medical courses scheduled to be held in September at Oak Ridge Institute of Nuclear Studies (NU, May '56, p. 24) has been changed; instead of external radioisotope measurement techniques, thyroid-uptake-calibration will be the subject of a one-week working conference. Moreover, it will be repeated weekly as long as there is demand for it; 20 can take the course at one time. The first course starts Sept. 24.

Fill 'er up ? Don't bother. The *Nautilus* has logged a distance "approaching 50,000 miles" without refueling, the Senate Armed Forces committee disclosed July 17, 18 months to the day after *Nautilus* first put to sea under nuclear power from Groton, Conn. Her first core is expected to be good for at least six more months before being replaced (NU, May '56, p. 74).

Legal problems to be discussed. The University of Michigan Law School has scheduled five workshop sessions on "Legal Problems of Atomic Energy" beginning Sept. 13 at Ann Arbor (*see p. 120*). Purpose is to assemble knowledgeable persons, evolve conclusions and recommendations on emerging unique legal problems of the field.

NICB postpones conference. The fifth "Atomic Energy in Industry" session sponsored by the National Industrial Conference Board has been postponed from Nov. 27–29 to March 14–15, 1957, and moved from New York to Philadelphia. Thus it will coincide with the second nuclear engineering congress of the Engineers' Joint Council.

. . . and schedules course. NICB will give its management course in nuclear energy for the seventh time Oct. 1–5 at the Biltmore in New York. The abridged, 9-to-5 version of a course previously held in the suburbs and with evening sessions is designed to accommodate commuters, and will permit 200 trainees instead of 75 to take the course.

US, UK nuclear chiefs on panel. During the annual meeting in Washington of the World Bank, Sir Edwin Plowden, chairman of the UK Atomic Energy Authority, and Lewis L. Strauss of the USAEC will participate in a panel discussion on atomic energy in economic development. Also on the panel, to be held Sept. 27, will be Sir John Cockcroft, head of research for AEA, and W. Kenneth Davis, AEC's chief of reactor development. Corbin Allardice, the Bank's advisor on atomic energy, will be moderator.

Vitro, Four Corners to collaborate. Under a long-term agreement between Vitro Corp. and Four Corners Uranium Corp. of Denver, Vitro will mill ore mined by Four Corners. The latter will furnish a minimum of 3,000 tons ore/mo and may increase to a maximum of 12,000 tons.

Forum sets meeting topics. Session subjects for its annual meeting at Chicago this September have been fixed by the Atomic Industrial Forum. Subject of the meeting will be "Management and Technology for the Atomic Industry"; individual sessions will be on economics of power reactor systems, impact of atomic energy on the law, new power reactor concepts, elements of nuclear power costs, reactor materials, radiation utilization, insurance, research and test services, information requirements, international developments. Congressman Melvin Price, Commissioner Harold S. Vance, Willis Gale of Commonwealth Edison, and West German Atomic Minister Franz Josef Strauss will be featured speakers.

New "campus" for Bureau of Standards. Long overcrowded at its outmoded and inadequate site on upper Connecticut Ave. in Washington, the National Bureau of Standards has selected a site for relocation: a 550-acre tract near Gaithersburg, Md., 18 mi NW of downtown Washington and 5 mi from Germantown, where foundation work is now proceeding on AEC's new headquarters building (NU, June '56, p. 24). Transfer of operations will take five years. The move will permit the Bureau to plan a more up-to-date plant for its standards, measurement, and research programs.

Cobalt information center founded. Battelle Memorial Institute has established a cobalt center at its Columbus, Ohio, labs to gather and disseminate data on advances in cobalt technology and uses.

AEC invites nuclear educators. A conference on nuclear engineering education will be sponsored by AEC at Gatlinburg, Tenn., Sept. 5–8. Presidents and deans of engineering of 150 colleges and universities have been invited. Purpose is to permit school administrators to discuss programs for students planning careers in the nuclear field.

Medical society growing. The Society of Nuclear Medicine now has 425 members, 250 of whom attended its third annual meeting at Salt Lake City. Eight regional groups were inducted as chapters. Discussion of problems of radiation protection, including fallout and reactor waste disposal aspects; of training adequate scientific manpower, and of the shortcomings of current techniques highlighted the meeting.

Navy, Kaiser study radioactive wastes. Kaiser Engineers, Oakland, Calif., has started an engineering study on radioactive-waste control for the Navy. Purpose is to evaluate several alternatives on absolute control and disposition of radioactive liquid and gaseous effluents from certain research operations to be undertaken by the Naval Radiological Defense Laboratory in San Francisco.

NOW AVAILABLE FOR ALL

The first nuclear reactor controls built by a non-AEC facility were supplied by **Radiation Counter Laboratories, Inc.** While continuing to fill these requirements of AEC, we have increased production to furnish reactor controls for other nuclear pioneers—some of whom are shown on this page.

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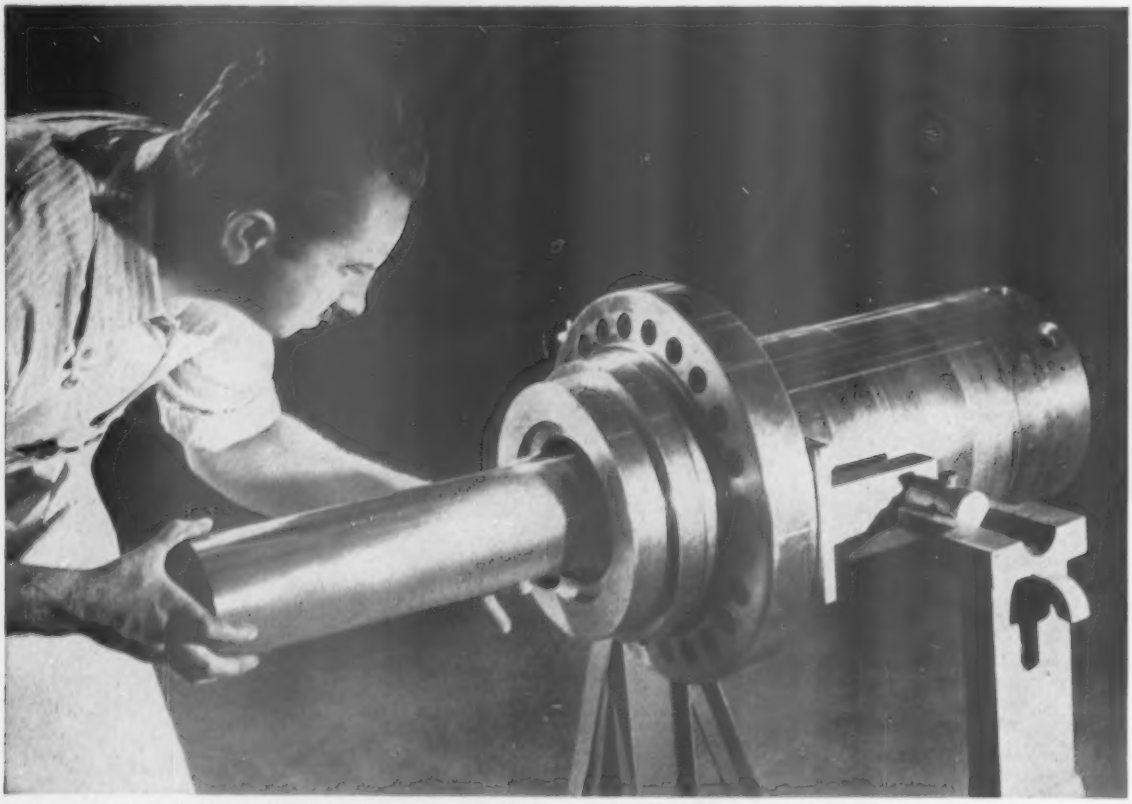

Inconel helped designers lick induction motor operating problem. This Inconel nickel-chromium alloy cylinder lines the bore of the stator, and another surrounds the rotor core . . . literally "canning" each. Yet there's no interference with magnetic fields. The motor was developed by Westinghouse Electric Corporation for the U. S. Government.

Inconel an essential in the "canned" pump

. . . resists corrosion and heat

A number of Atomic Energy Commission projects now employ hermetically sealed pumps. They circulate reactor coolants in high-temperature, high-pressure closed systems.

This type of pump contains all moving parts in a pressure-tight cell. It houses the impeller driven by an induction motor, together with stator and rotor in separately sealed "cans."

It is well named a "canned" motor-pump. And, with two metallic walls between stator and rotor, it depends fundamentally on Inconel* nickel-chromium alloy for successful operation.

Inconel an essential

As shown above, a thin liner of Inconel alloy is inserted in the stator to seal it from the coolants pumped. A similar liner protects the rotor.

The designers, Westinghouse Electric Corporation, selected Inconel nickel-chromium alloy because it meets four important demands:

1. **It resists corrosion by aggressive high-purity water**
2. **It resists corrosion by certain liquid metals**
3. **It has the necessary non-magnetic properties**
4. **It has high electrical resistivity**

Other advantages

Inconel alloy is structurally stable. It is not subject to embrittlement on prolonged heating in non-sulfidizing atmospheres.

Inconel alloy is chemically stable. It resists damage by oxidation, carburization and other forms of high-temperature attack.

Inconel alloy is mechanically stable. It retains useful properties to 2100°F. and over, in some applications. It resists grain growth and withstands thermal shock.

Inconel alloy is easy-to-work . . . easy to form, machine, weld . . . available in all commercial wrought forms.

Learn how Inconel nickel-chromium alloy may help you. *Send for Inco's 24-page Technical Bulletin T-7.* It gives data on properties, available forms, and how to fabricate. It's yours for the asking. And if you have a specific high-temperature problem, call on Inco's Technical Service Section . . . giving full details when you write.

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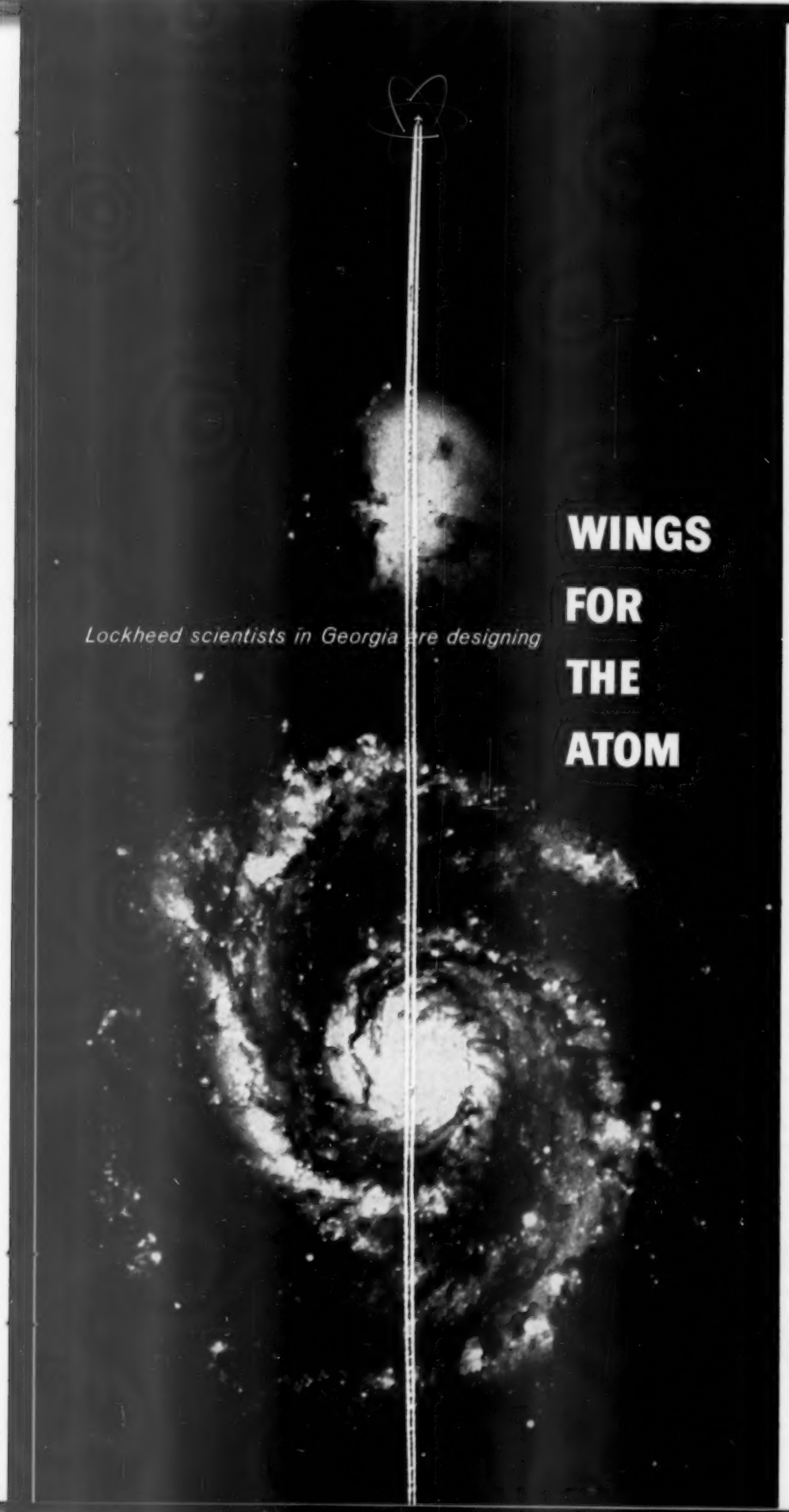

Lockheed scientists in Georgia are designing

WINGS FOR THE ATOM

Domesticating the atom to serve mankind has intrigued science for over a decade. One top priority application, secretly under way for several years at Lockheed: developing a nuclear-powered plane as different from present types as a supersonic jet is from the first stick-and-wire biplane.

IMAGINE A GIANT AIRCRAFT SOARING ALOFT, NOT WITH TONS OF GASOLINE, BUT WITH A URANIUM FUEL SUPPLY NO BIGGER THAN A HANDFUL OF GRAVEL. EVENTUALLY, SUCH A PLANE-OF-THE-FUTURE—WITH THIS SCANT FUEL SUPPLY—WILL GIRDLE THE GLOBE NON-STOP BETWEEN SUNRISE AND SUNSET.

More than a dream, this incredible aircraft is now being developed by Lockheed for the U.S. Air Force despite problems of propulsion, structures and materials, thermodynamics, crew survival, producibility and maintenance unique in aviation. Old concepts are being shelved, traditional solutions rejected. *The kind of aeronautical advances that once took a generation of research are now being telescoped into a few months, even weeks.*

Soon several hundred nuclear scientists and engineers from Lockheed's Georgia Division will move to the North Georgia mountain country. There, on a vast site—some 40 miles from U.S. Air Force Plant No. 6 at Marietta, operated by Lockheed—will be built the nation's largest facility for the development of atomic-powered aircraft.

The exact status today of the atomic plane is still a military secret. But this much can be said: The first nuclear aircraft to blaze across America's skies may not look essentially different from conventional planes, but functionally it can only be described as revolutionary. And after the nation's military requirements are met, the transports then available to you as a traveler will rank among the truly exciting events of aviation history.

YOU YOURSELF MAY THEN TRAVEL ABOARD A NUCLEAR-POWERED AIRLINER—CROSSING THE COUNTRY IN AN HOUR OR TWO, OR SPANNING THE ATLANTIC IN LESS TIME THAN IT NOW TAKES TO GO FROM CHICAGO TO NEW YORK.

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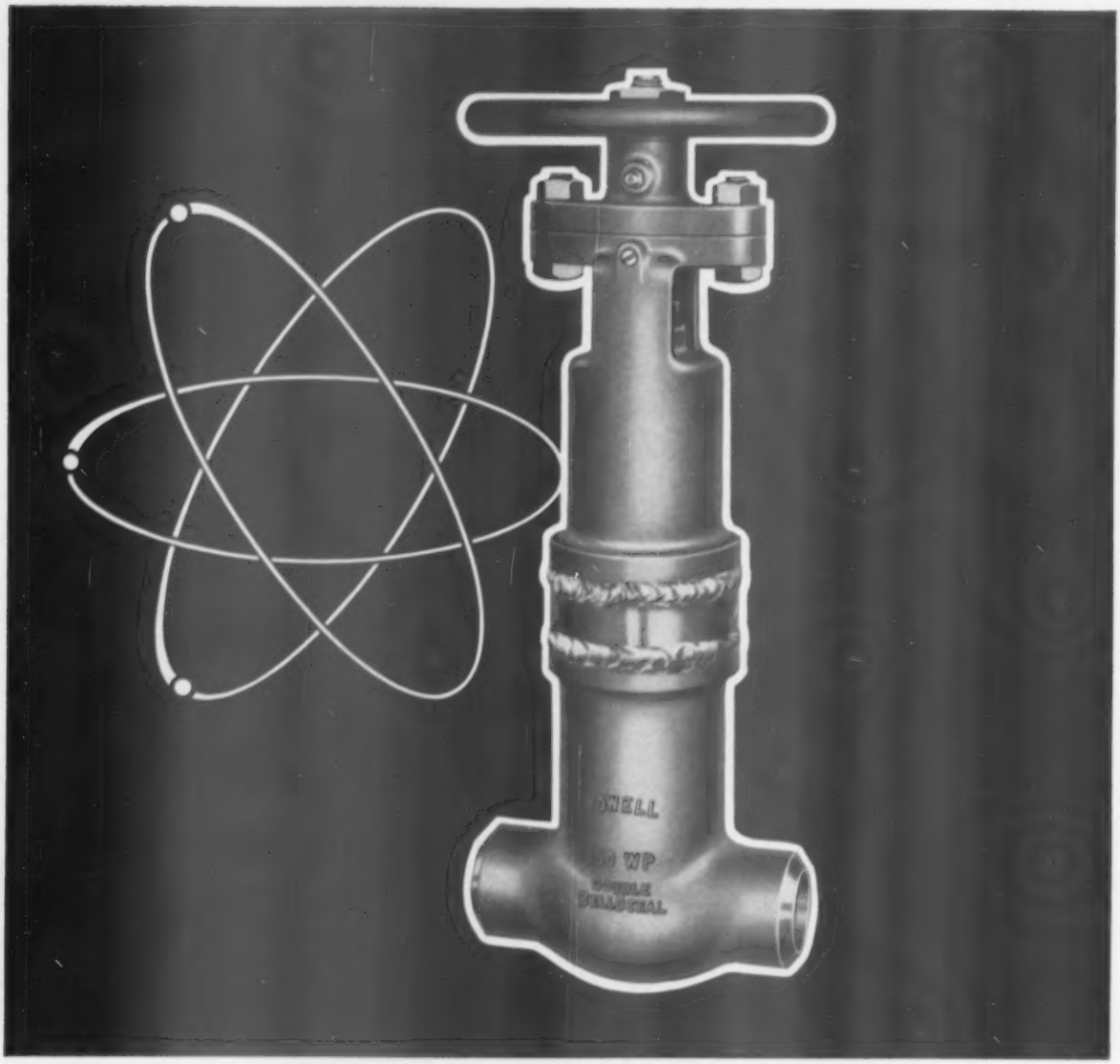

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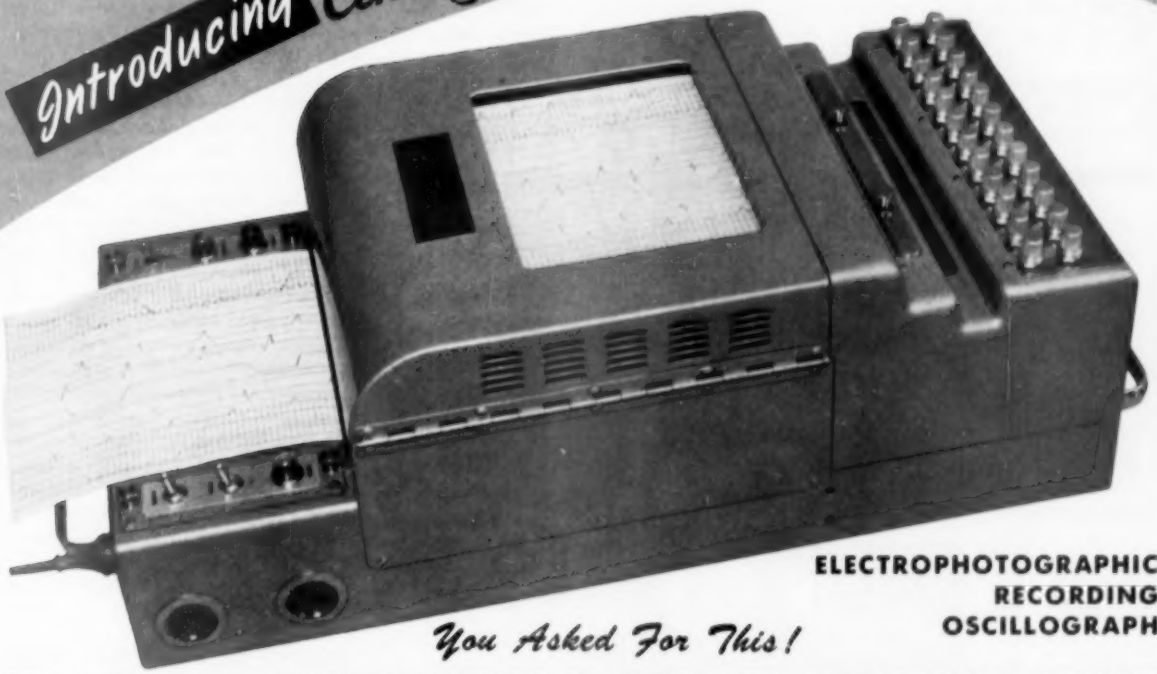

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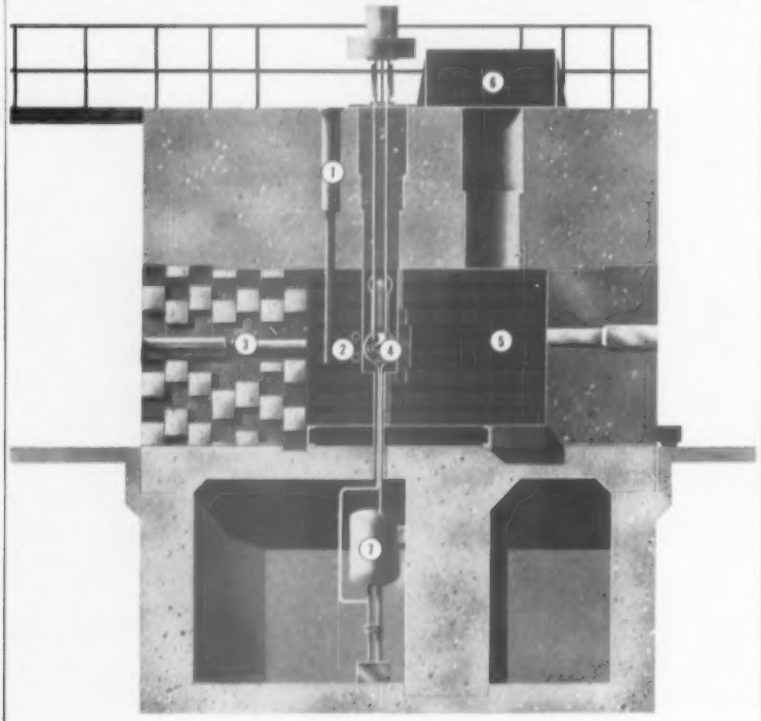
NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Aqueous, homogeneous type nuclear reactor being built for Japan

The first nuclear reactor for the Far East is being built by ATOMICS INTERNATIONAL for the Atomic Energy Research Institute of Japan. The reactor will be located near Tokyo. When the reactor starts operating early in 1957, a full program of research into the peaceful applications of nuclear energy will begin. This program includes the production of radioisotopes, studies in neutron activation, neutron diffraction, radiation effect on materials and training in reactor techniques.



Solution Type Research Reactor for Japan.

1 – Vertical thimble
2 – Pneumatic tubes
3 – Beam Tubes
4 – Central exposure facility
5 – Horizontal thermal column
6 – Vertical thermal column
7 – Gamma radiation area

At a rated power of 50 kilowatts, this solution type reactor will produce a peak thermal neutron flux of 1.7 x 10^{12}/cm² sec. Equipped with a five foot graphite thermal column, it will provide an extensive source of slow neutrons. Additionally, the room beneath the reactor housing the gas handling system has been designed to provide neutron-free gamma irradiation. This facility, ideally suited for biological and chemical experiments, will provide 50,000 curies of radioactivity in Xenon and Krypton gases circulating in the system.

The core of the reactor is a stainless steel sphere with a diameter of approximately 12 inches, filled with a uranyl sulphate solution. The fuel investment is approximately 1000 grams of Uranium^{235}. The reflector around the core consists of graphite stacked in a rectangular steel tank 5 feet high, 5 feet wide and 8 feet long. Appropriate holes for experimental facilities and instrumentation are located in the graphite. Five feet of dense concrete provides a shield around the reflector tank.

Instrumentation control is provided by two types of sensing elements which give neutron level information. In the power range up to approximately 1 watt, two fission chambers are employed. In the power range of approximately 0.1 to 50,000 watts, two gamma compensated ionization chambers are used. One of these chambers is fed into a shutdown channel and an electrometer which in turn sends a signal to the power level recorder. Power level is automatically maintained by feeding an error signal from the level recorder to a servo-amplifier which drives the regulating rod motor in the proper direction to correct error. The other ionization chamber feeds a logarithmic amplifier, and period shutdown circuit.

The core cooling system consists of a closed, recirculating system using demineralized light water. The core cooling loop includes about 90 feet of stainless steel tubing, the associated pump, valves and piping, and a heat exchanger to transfer the heat to a secondary cooling system.

ATOMICS INTERNATIONAL, a division of North American Aviation, Inc., is a major reactor builder–experienced in the design, construction and operation of nuclear reactors for research and the production of power. A reactor similar to the one scheduled for Japan has been installed for the Armour Research Foundation of the Illinois Institute of Technology in Chicago. It is one of several in-action nuclear reactors designed and built by ATOMICS INTERNATIONAL.

If you are interested in any phase of reactor technology, ATOMICS INTERNATIONAL is staffed and equipped to serve you. Please write: Director of Technical Sales, Department N-N4, ATOMICS INTERNATIONAL, P.O. Box 309, Canoga Park, California. Cable address: ATOMICS.

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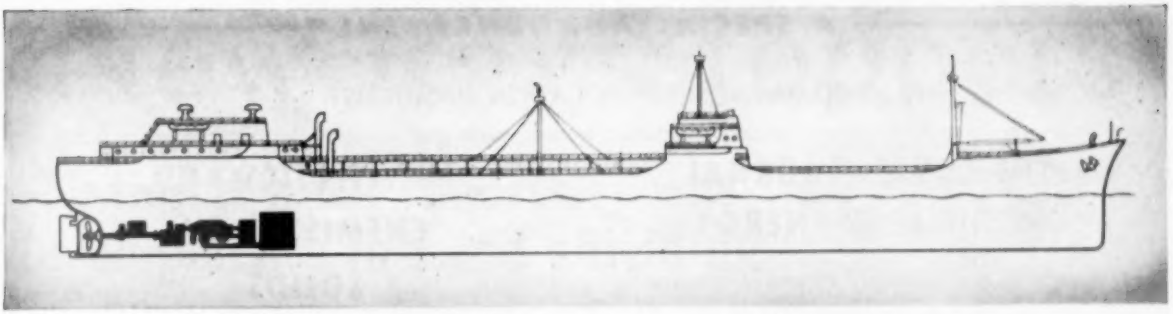
PIONEERS IN THE CREATIVE USE OF THE ATOM



A CCGCR propulsion system as it would appear in a tanker.

PROGRESS REPORT NO. 2

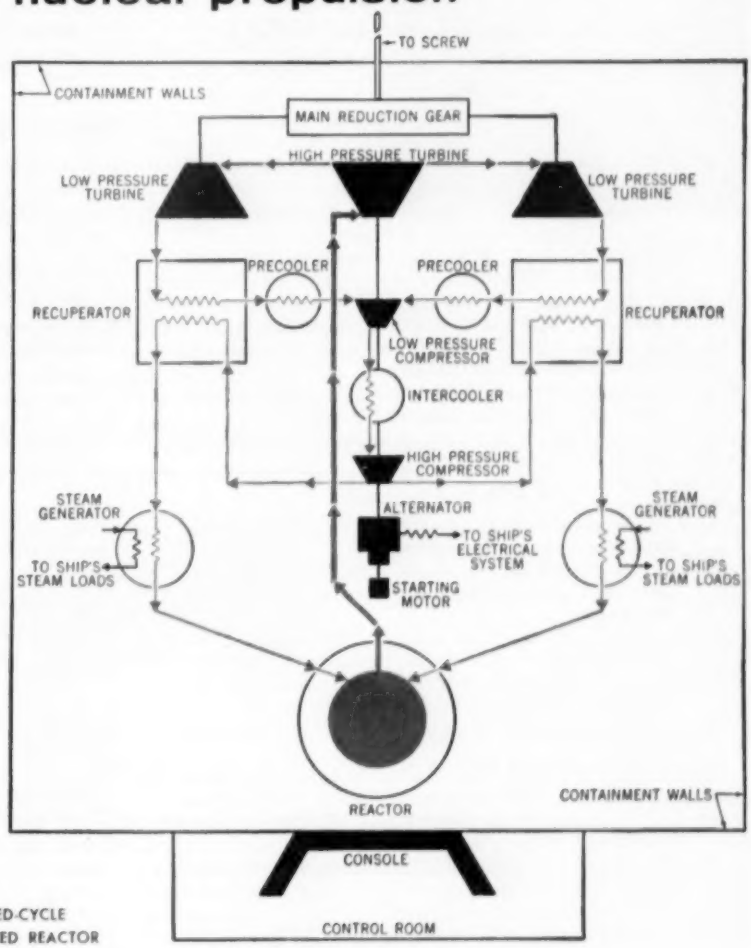
THE CLOSED-CYCLE GAS-COOLED REACTOR
...for nuclear propulsion

Ford Instrument Company is continuing its investigations of the Closed-Cycle Gas-Cooled Reactor, "The Eighth Reactor Type." Latest findings show that the CCGCR has many attractive possibilities for ship propulsion as well as for stationary power plants.

Illustrated on the right is a schematic of a ship propulsion system as visualized by FICo.

There are definite advantages which will make this plant attractive to ship operators. Among these is the drastic reduction of fuel storage facilities. This reduction in fuel carrying requirement can be reflected in additional revenue carrying capacity. In addition, such a system should offer:

- **Low Cost**
- **High Thermal Efficiency**
- **Maximum Safety**
- **A Minimum of Moving Parts**



Simplified Flow Diagram showing major components of ship propulsion system.

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Some of the papers to be published in Vol. 3 of the Journal of Nuclear Energy

Part I

H. A. BETHE and R. E. CARTER: Inelastic Cross Sections for Fission Spectron Neutrons, IV.

R. B. LEACHMAN and H. W. SCHMITT: The Cross Section for U^{235} Fission by Fission Neutrons.

R. PERSSON *et al.*: Experimental Pile Experiment with Natural Uranium and Heavy Water.

G. W. GREENWOOD and B. SHARPE: The Effect of Thermal Gradients on Metallic Slurries.

C. P. CAILLET and J. CARPENTIER: La Dynamique de l'Empoisonnement d'un Reacteur par le Xenon.

R. BATCHELOR and H. R. McK. HYDER: The energy of delayed neutrons from fission.

R. P. FEYNMAN, F. DE HOFFMAN and R. SERBER: Dispersion of the neutron emission in U^{235} fission.

N. J. PATTENDEN: The slow neutron total cross section of U^{233}.

Part II. (Supplement)

I. V. KURCHATOV: On the Possibility of Thermonuclear Reactions in a Gas Discharge.

M. A. LEONTOVICH and S. M. OSOVETS: On the Mechanism of Current Constructions in a High-Current Discharge.

S. YU. LUKYANOV and S. I. SINITSYN: Spectroscopic Investigations of High-Current Discharge in Hydrogen.

V. S. VAVILOV: Solar Batteries (on the Conversion of Solar into Electrical Energy by Means of Photocells).

V. A. POLIKARPOVA: Nenadkevit—A New Uranium Silicate.

A. S. KUZMINSKY, T. S. NIKITINA and V. L. KARPOV: Some Aspects of the Vulcanization of Rubber by Radiation.

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GERT EHRLICH: The Mechanism of Chemisorption on Metals.

E. O. KANE: Energy Band Structure in P-type Germanium and Silicon.

I. LIFSHITZ *et al.*: Galvanomagnetic Effects in Metals.

I. LIFSHITZ *et al.*: Paramagnetic Resonance in Metals.

E. P. WOHLFARTH: The Electronic Properties of Nickel-Palladium Alloys.

JOHN B. GIBSON: The Effect of Short-Range Order on Residual Restivity.

G. DRESSELHAUS: Effective Mass Approximation for Excitons.

HARRY LETAW, JR: Thermal Acceptors in Germanium.

J. A. HOFMANN, A. PASKIN, K. J. TAUER and R. J. WEISS: Analysis of Ferromagnetic and Antiferromagnetic Second Order Transitions.

ARTHUR C. DAMASK: Residual Resistivity vs. Short-Range Order in Cu_3Au.

A. I. SCHINDLER, R. J. SMITH and E. L. SALKOVITZ: Preliminary Electrical Resistivity Measurements of the Nickel-Palladium Alloy System.

L. M. MATARRESE and CHIHIRO KIKUCHI: Paramagnetic Resonance Absorption of Mn^{++} in Single Crystals of Zincblende.

E. BURSTEIN, G. PICUS, B. HENVIS and R. WALLIS: Absorption Spectra of Impurities in Silicon-I. Group III Acceptors.

G. PICUS, E. BURSTEIN and B. HENVIS: Absorption Spectra of Impurities in Silicon-II. Group V Donors.

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New Ray Stoppers

National Lead reports recent developments in Lead shielding

Improved casting process permits void-free shielding of heavy water filters

Internals only, need disposal in versatile "*Fulflo*" unit

Until very recently, separate shields of rolled or extruded lead were considered standard for vessels processing "hot" fluids. It was assumed that only with this type of construction was porosity prevented and positive protection assured.

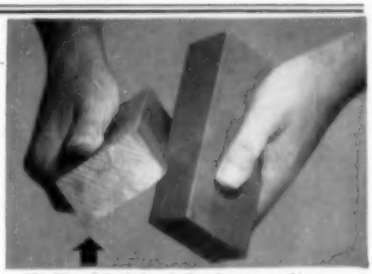
Now, however, integral steel jackets, lead-filled by an improved void-free National Lead casting process, may take over. Poured lead shielding, formed by this method, absorbs radiation as effectively as rolled or extruded lead. What's more, less lead is needed than with separate shields. Installation is less expensive, equipment more mobile.

Practicality of design and method were demonstrated by 18 *Fulflo* Filters, installed in a government plant, which were designed and built by Commercial Filters Corporation, Melrose, Massachusetts with void-free lead shielding poured by National Lead. These units (see cutaway view) filter 200 gpm of heavy-water-rich fluid. The integrated shields permit shells to be decontaminated and re-used indefinitely. Only the internals need periodic disposal. Shielding efficiency is said to be very high.

Void free lead shielding shown by solid black areas above

Slave-handled drawers for radium equipped with novel lifting hook

These new drawers for hospital radium safes are designed for slave manipulation. Drawer has two mating stainless-clad lead sections that slide apart. Upper section contains a recessed lifting hook. Produced by National Lead.



Hi-Hard brick (*left*) dents ordinary brick (*right*)

National Lead now producing "Hi-Hard" lead brick

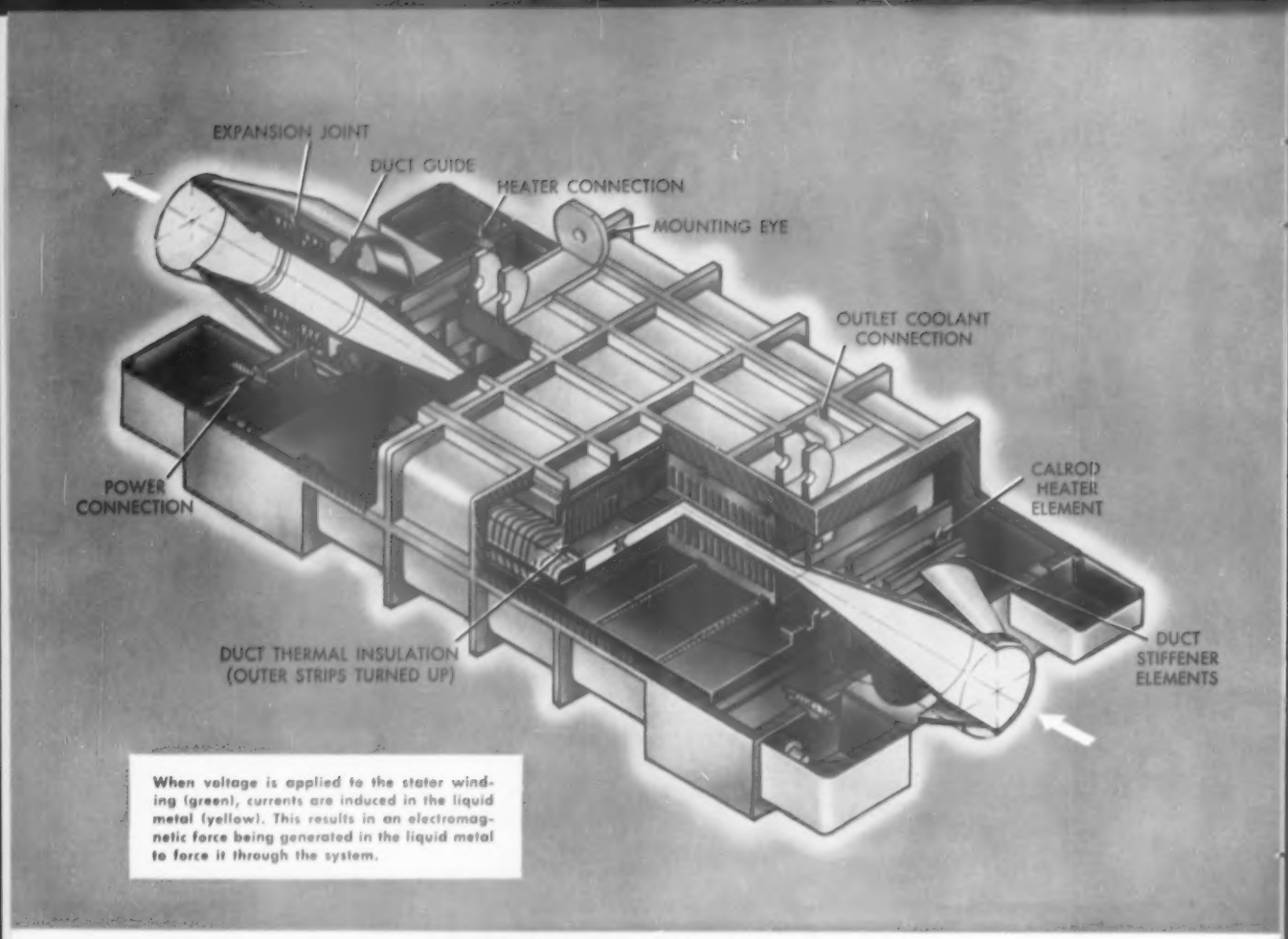
Extruded lead brick with a Brinell hardness of 19 minimum are being produced by National Lead. Ordinary lead, with a density of 11.35, runs around 4 to 5 Brinell. Density of new "Hi-Hard" lead brick is 11.14. Thus there is a gain of better than 400% in hardness while retaining 98.2% density of ordinary lead. What this means to hot labs and other users of moveable lead shielding is obvious—fewer brick scrapped because of nicks and round corners, tighter walls, lower over-all costs for shielding.

Low activity lead for sensitive counting now available from National Lead

For applications where even the normally low emission of lead (generally from Pb-210) is objectionable in accurate, sensitive counting, unusually low activity lead is now available. If you have use for this "aged" lead, write nearest Company office listed below.

National Lead Shielding

NATIONAL LEAD COMPANY: New York 6; Atlanta; Baltimore 3; Buffalo (Depew P. O.); Chicago 80; Cincinnati 3; Cleveland 13; Dallas 2; Philadelphia 25; Pittsburgh 12; St. Louis 1; Boston 6 (National Lead Co. of Mass.); Los Angeles 23 (Morris P. Kirk & Son, Inc.); Toronto, Canada (Canada Metal Company, Ltd.).


EXPANSION JOINT
DUCT GUIDE
HEATER CONNECTION
MOUNTING EYE
OUTLET COOLANT CONNECTION
POWER CONNECTION
CALROD HEATER ELEMENT
DUCT THERMAL INSULATION (OUTER STRIPS TURNED UP)
DUCT STIFFENER ELEMENTS
When voltage is applied to the stator winding (green), currents are induced in the liquid metal (yellow). This results in an electromagnetic force being generated in the liquid metal to force it through the system.

A-C ELECTROMAGNETIC LINEAR INDUCTION PUMP

Design experience in atomic motors pays off...

General Electric electromagnetic pumps operate successfully with zero leakage

Engineered and manufactured to provide zero leakage in atomic reactors, General Electric EM pumps are a revolutionary step in the advancing field of nuclear power. Their simple design, rugged construction and virtually maintenance-free characteristics have enabled them to operate under the most adverse conditions.

General Electric's Medium Induction Motor Department in Schenectady, N. Y. is playing a major role in the free-world's atomic industry. In 1948, G-E motor engineers developed the first practical, large size EM pump. And recently, they furnished the "precision-built heart"—the electromagnetic pumps—for the atomic submarine *Seawolf*. Today, the largest a-c EM pump ever built—a unit capable of delivering up to 5000 gpm—is on the test floor of the Medium Induction Motor Department.

Basically, electromagnetic pump operation is similar to that of an a-c squirrel cage induction motor. However, in these pumps, a column of liquid metal has replaced the conventional rotor. Thus, the problems of shaft warpage, bearing failure and faulty running seals have been eliminated. Smooth, continuous, and accurate control of flow is assured.

Originally designed for radioactive and high-temperature systems, electromagnetic pumps are now available for use in liquid metal laboratories and industrial processes where continuous operation and zero leakage are demanded. General Electric's development experience and manufacturing facilities . . . the same experience and facilities which have produced more large electromagnetic pumps than any other manufacturer . . . are ready to work for you—*now*. For more information on EM or Canned Motor pumps, write Section 873-2, General Electric Company, Schenectady 5, N. Y.

Progress Is Our Most Important Product

GENERAL ELECTRIC

NUCLEONICS AUGUST, 1956

Jerome D. Luntz, *Editor*

52 Mills vs. 7 Mills

EXCEPT for the major squabble over whether the U. S. should have built the H-bomb, the military side of the U. S. atomic energy program has moved ahead with a single-mindedness of purpose, to build more and better weapons. But right from the start, the reactor development effort has not enjoyed such clear-cut direction. Instead there have been numerous stops and starts and changes in direction.

This goes right back to the earliest days under the Army when the Daniels gas-cooled power pile project was undertaken with great enthusiasm and then dropped like a hot potato. Then, in succession, there were: the internal fight on whether we should have a nuclear Navy with the subsequent decision that has resulted in our unquestionable world lead in this area; the start of an aircraft nuclear reactor project, with a later attempt to throttle it, and with an eventual shift in responsibility and emphasis so that we are only now getting up steam on it; the start of an intermediate power breeder project and the dropping of it; and finally, the genesis of our first central-station reactor project (the PWR) in an abandoned military reactor (the CVR).

No wonder that, after innocently thinking that the U. S. was at last embarked on a civilian nuclear power program that was appropriate for it in size and scope, we now suddenly find the underlying premise on which the program was built being questioned and attacked. This is the premise that, because this country doesn't have an urgent need for developing a new source of low-cost power for domestic use, we are going at achieving economic nuclear power at as fast a rate as it makes sense to do so financially. Instead, we are told that it is more important for us to match kilowatt for kilowatt of planned nuclear plant capacity with Russia and the United Kingdom. This, of course, is what Senator Gore is trying to achieve in his legislation that, at this writing, is being debated in Congress.

UNDOUBTEDLY, part of the reason for the current confusion over objectives is that the cornerstone—at least from the propaganda point of view—of our civilian power program is the PWR. This is the only full-scale civilian power reactor that will be ready for operation in this country in less than three years—it is scheduled to go critical next year. And this is the reactor that is most frequently pointed to as evidence that we're moving right along.

The confusion about PWR is that it was conceived as our prime entry in a race with the USSR (and presumably the UK) because it was said to encompass enough known technology so that it could be built pretty fast. But a complicating factor is that it was also recognized and readily admitted that there wasn't a hope in the world the cost of power from PWR could be remotely competitive anywhere in the world. Thus we said that PWR was going to provide us with sorely needed engineering knowhow.

In fact, Philip A. Fleger, board chairman of Duquesne Light Company, operator of PWR, has gone so far as to say, "The actual cost of electricity produced by developmental plants such as Shippingport will be of no significance whatsoever. On the other hand, with the knowledge gained from the construction and operation of these plants it will be possible to estimate the cost of constructing and operating plants of the same type on a nondevelopmental basis."

But now there are some who are losing sight of this reasonable point of view that, from the standpoint of common technical sense, PWR can only be useful in giving us engineering data—an important purpose, as pointed out by Fleger. Instead, we're bandying about numbers on what power from the PWR will cost. One official has said that the first core of PWR will result in power costing 52 mills per kilowatt-hour. No matter how you slice it, no matter how you look at it, this is high cost power!

And the eyes of the world that are on us seeking guidance as to what directions to turn in, where to get assistance, are shocked that the U. S., the supposed world leader in atomic energy, will be producing 52-mill power in its first central-station nuclear power plant.

This would not be terribly bad were it not for the fact that the first British power reactor (at Calder Hall) has already gone critical and that the British maintain that the net cost of this power will be 7 mills.

Actually, there is considerable confusion between Calder Hall and the first UK civilian power reactor planned for completion in 1960 or 1961. The Calder Hall plants are designed for optimum plutonium production, and the cost of the byproduct power can be anything desired according to the price set for the plutonium. PWR is aimed at attacking the problem of power-only reactors directly. It is expected that Calder Hall will cost more to build than PWR (despite lower wage rates in the UK) and will put out less power. There seems to be no basis whatever for saying the Calder Hall reactors show any advantage technologywise or costwise over PWR. Neither will make cheap power when operated for power only.

And one key U. S. official made this prediction to NUCLEONICS: "The PWR will probably make much more of a contribution towards ultimate achievement of economic nuclear power. The UK figure of 7 mills would be the equivalent of about 11 mills for U. S. financing and prices. By the time the UK has achieved such a level for power-only reactors (sometime after 1961), the U. S. should have power reactors in operation producing power at a cost substantially below this."

NOTWITHSTANDING all of the above, people in other countries are confused as to why there is such a discrepancy in cost. This has apparently been part of the reason why some countries are now turning to the British for assistance.

What this all boils down to is that it doesn't make too much sense to talk today about what nuclear power will cost tomorrow. We're in the midst of a tremendous building program that will give us cost data. It will be time to talk when we have some data in hand.

Where Reactor Development Stands Today

Excluding reactors for Pu production and aircraft propulsion, today's 45 reactors will be joined by about 127 more by 1960. New technical discoveries have made more reactor types look promising. Thus, although competitive nuclear power is still "on paper," continuing progress points toward an encouraging future

By JAMES A. LANE
Oak Ridge National Laboratory
Oak Ridge, Tennessee

JUST HOW FAR the reactor business has progressed since the first pile went critical in December of 1942 is shown on the cover. The figures for the years 1956 through 1960 correspond to reactors now planned or being constructed, although in the case of research reactors, the numbers of reactors constructed after 1958 have to be estimated. This is because construction of all research reactors announced will be completed before that time.

The numbers do not include the 13 U. S. large-scale production reactors, foreign production reactors, or aircraft-propulsion reactors.

Non-U. S. Power Programs

As shown by the partial list in Table 1, many countries have made a good start toward the development of nuclear power. In most cases, emphasis is on reactors fueled with natural uranium. This is partly because the U. S. offer to make available 20,000 kg of enriched uranium for foreign power reactors has not yet had an effect on announced power-reactor programs, and partly because many countries believe that it is more economical to operate with natural uranium and advantageous to remain independent of the availability of enriched fuels.

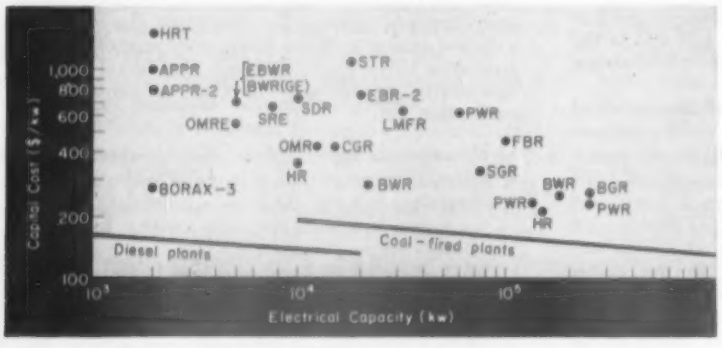


FIG. 1. Capital costs of U. S. nuclear and conventional power plants

Since natural-uranium-fueled reactors are necessarily very large, the use of some enrichment considerably increases the flexibility of the reactor design from the standpoint of choice of coolant, cladding, and size of reactor. Even if the reactor requires some enrichment for the initial loading, continued operation may be possible using only natural uranium plus plutonium from spent fuel.

Russia. The Russian program is worthy of special mention. At Geneva, the first Russian nuclear power plant was described; it uses a water-cooled graphite-moderated reactor (*1*). In reality, this power plant is a pilot plant and is not claimed to be economical.

Early this year, the Soviet Union announced that it had plans to build during 1956–60 nuclear-power stations with a total capacity of 2–2.5-million kilowatts. I. V. Kurchatov, a leading member of the USSR Academy of Sciences, reporting to the 20th Congress of the Communist Party in Moscow on February 22, stated, " . . . Two atomic electric stations with a total capacity of 1-million kw will be built in the Urals by 1960, and near Moscow there will also be built an atomic station with a capacity of 400,000 kw. In addition, up to

TABLE 1 — Non-U. S. Power Reactor Programs

Reactor type	Power (Mw) Heat	Power (Mw) Elec.	Cost (10^6)	Completion date
Austria —	—	10	4	—
Belgium				
Pressurized water	—	11.5	4.6–5.7	1958
Canada				
Nat. U, D_2O	—	20	11	1958
France				
Air, graphite	—	5	—	1956
Two CO_2, graphite	—	25	—	1957
Norway				
Nat. U. D_2O	20*	0	3.5	1959
Sweden				
Nat. U, D_2O	75*	—	—	1960
Nat. U, D_2O	90*	—	—	1960
Nat. U, D_2O	71*	13	—	1961
Three—	—	75–300	—	1962
Britain†				
Air, graphite; Windscale‡	—	0	—	—
Stage-0:§				
CO_2, graphite; Calder Hall	—	70	—	'56, '57
CO_2, graphite; Calder Hall	—	70	—	1958
CO_2, graphite; Chapel Cross	—	70	—	1958
CO_2, graphite; Chapel Cross	—	70	—	—
Stage-1:¶				
CO_2, graphite; Bradwell	—	150	—	1961
CO_2, graphite; Berkeley	—	150	—	1961
CO_2, graphite; Glasgow	—	150	—	1961
*Stage-2:***				
Na, graphite; 3 sta.	—	450–750	—	1963
Na, graphite; 6 sta.	—	750	—	1965
*Stage-3:***				
Aqueous homogeneous	—	—	—	—
Fast breeder	—	—	—	—
USSR††				
First experimental plant:				
H_2O, graphite	—	5	—	1954
First large developmental plant				
Pressurized water, graphite	—	100	—	end 1956‡‡
Pilot plants ("up to ten" types)§§				
H_2O-moderated and-cooled		70	—	1958–60
Graphite-moderated; H_2O-cooled	>1,000	200	—	1958–60
D_2O-moderated, CO_2-cooled¶¶	>1,000	200	—	1958–60
H_2O boiling	—	50–70	—	1959–60
Homogeneous, U^{233}-Th breeder	—	50–70	—	1959–60
Graphite-moderated, Na-cooled	—	50–70	—	1959–60
Fast breeder, Na-cooled	—	50–70	—	1959–60
Three full-scale power plants in Urals				
Two, type unspecified	—	500	—	1960
One, type unspecified	—	400	—	1960

* For process heat. † Total of 23 reactors (some stations have two reactors); total installed nuclear capacity to be about 2,000 Mw. ‡ Two reactors used for Pu production. § For Pu + power. ¶ For power + byproduct Pu. ** Power only. †† Over-all goal is 2,000–2,500 Mw nuclear electrical capacity by 1960. ‡‡ Described by D. I. Blokhintsev at Geneva conference. §§ Two types remain unspecified. ¶¶ Discussed by V. V. Vladimirsky at meeting sponsored by National Industrial Conference Board, New York, October, 1955.

10 types of reactors with individual electric capacities from 50 to 200,000 kw will be built by 1960, ..." In an April talk at Harwell, Kurchatov gave more details of these plants. The program is summarized in Table 1.

As in our own program, the large-scale plants use the more conventional nuclear systems and the smaller pilot plants use the advanced types of reactors. These experimental reactors will have a combined electrical output of about 1,000 Mw, which, with the very large plants previously mentioned, will provide the Russians with an installed nuclear electrical capacity of 2,000–2,500 Mw by 1960. Although some confusion exists concerning the

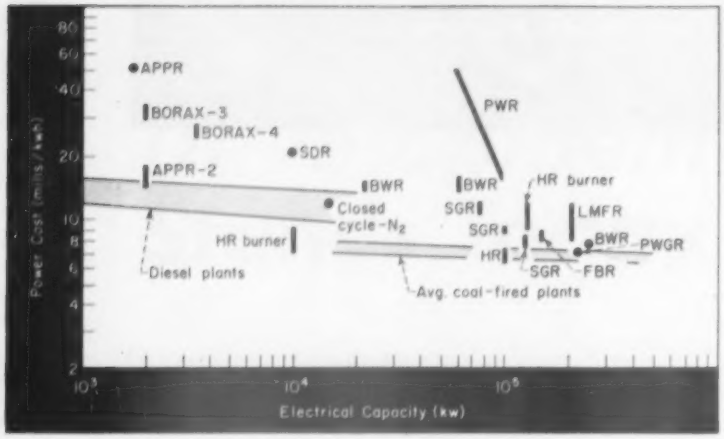


FIG. 2. Costs of power from U. S. nuclear and conventional plants

electrical capacities of individual plants, indications are that capacities given in Table 1 are substantially correct. This very ambitious program, though greater in numbers of electrical kw than our own program, is certainly not as diversified.

Britain. The British nuclear-power program belongs in a class by itself. Drawing on experience with the graphite plutonium-production piles, the British have evolved a program of reactor construction that permits them to move ahead while the development program also proceeds. This dual-purpose route to nuclear power has been suggested as a means of expediting the U. S. program. However, it was not adopted in the U. S. due to the fact that sizable plutonium-production facilities were available already and a dual-purpose system requires essentially complete government control. Adoption of this approach might have delayed industrial participation in our program.

The schedule for the construction of U. K. power reactors indicates that the installed nuclear plant capacity in the U. K. will be more than 2,000 Mw of electricity by 1965.

The U. S. Power Program

As shown in Table 2, U. S. power reactors can be divided into three classes: (a) those financed entirely by the AEC, (b) those financed jointly by AEC and industry, and (c) those financed entirely by industry.

AEC-financed.* In most of the five cases listed, each type includes a reactor experiment and a prototype reactor, the low-power versions serving to test the nuclear characteristics of the reactor; the high-power versions test engineering characteristics.

Los Alamos. An AEC-sponsored power-reactor program that involves more venturesome types of reactors is not shown in the table. At Los Alamos, three experimental power reactors are being developed, one of which, the LAPRE-1, has already been operated. This reactor is fueled with a solution of enriched UO_2 in aqueous phosphoric acid. Because of the highly corrosive nature of the solution, all equipment in contact with it has to be gold-plated or made of platinum. In assembling the LAPRE-1, the gold plating on a portion of the cooling coils was damaged and this portion corroded through in about 5 hr. But the Los Alamos group feels that this system can be made reliable and is going ahead with a new set of cooling coils. The second test is scheduled for this June (*2*).

LAPRE-2 uses a comparable fuel system, but the reactor operates with natural circulation rather than forced circulation used in LAPRE-1. Most of the components are completed and final assembly is expected to be accomplished late this summer.

A third reactor, the LAMPRE, is being built to test the concept of using a molten plutonium alloy as the fuel. A 1-Mw pilot model will be completed in 1959 and the design of 50–100-Mw-scale reactors is being studied. High temperatures will be possible with this system and breeding using such a fuel is potentially possible.

Joint AEC-industry financed. For the experimental and prototype reactors being developed jointly by industry and AEC, it will be noted that, in some cases, industry is bearing the major share of the costs and, in other cases, most of the cost is financed by AEC (*3*).

"Second round." An AEC invitation for industry to consider a second round of power-demonstration reactors involving small-scale plants resulted in seven proposals, each using a different type of reactor. The two proposals made by the Elk River Association and the Wolverine Electric Cooperative have been "approved in principle" by AEC. Contracts for AEC assistance, which involves 75% of the costs for design, development, and construction of the facilities, will be contingent on approval of the Rural Electrification Administration loans requested by the cooperatives. The remaining proposals are still being evaluated by the AEC staff.

Industry financed. Permits for the construction of three of these reactors were issued on May 4 and May 15 to the Consolidated Edison Co., the Commonwealth Edison Co. and the General Electric Co. Each construction permit allocates special nuclear material to be made available over a 40-yr period.

The amount required for the Consolidated Edison reactor for this period is estimated to be 5,700 kg U^{235}, and for the Commonwealth reactor, 8,300 kg U^{235}. Annual requirements for the Consolidated reactor amount to 155 kg U^{235}. However, 140 kg of U^{233} are produced after equilibrium is reached in about two years of operation, by neutron capture in the thorium, of which 62 kg are consumed. The Commonwealth reactor uses 225 kg U^{235}/yr during steady-state operation, to be reached about four years after startup. Completion dates of September 30 and October 1, 1960, are stipulated in the permits.

The pilot model of the G.E. boiling-water reactor will be built at G.E.'s new nuclear laboratory near Livermore. This plant initially will have a generating capacity of 3,000 kw (elec.) and an ultimate capacity of 10,000 kw, and use a net of 29 kg U^{235} over a 7-yr period. The remaining two reactor projects are still in the

* SRE and OMRE are not included here since their construction is financed partly by industry.

TABLE 2—U.S. Power-Reactor Programs

Reactor type	Power (Mw) Heat	Power (Mw) Elec.	Cost* (10^6)	Completion date	Contractors
AEC-financed projects					
Boiling water:					
Borax-3	15	2–3	0.6	1955	ANL
EBWR	20	5	3.6	1956	ANL, Sargent & Lundy
Pressurized water:					
APPR	10	2†	2.1	1957	ORNL, Alco
ALPR	~1	~0.2	—	—	ANL
Fast breeder:					
EBR-1	1.4	0.17	2.7	1951	ANL
EBR-2	62.5	17.5	15.3	1958	ANL
Aqueous homogeneous:					
HRE	1.0	0.15	1.1	1952	ORNL
HRT	5–10	1–2†	~3	1956	ORNL
Liquid-metal fueled:					
LMFRE	5–10	—	—	1959	BNL, Babcock & Wilcox
Joint AEC-industry-financed projects					
Pressurized Water (PWR)	264	60	15.5; —: 32.2; 59.6‡	1957	Westinghouse, Duquesne
Sodium Graphite (SRE)	20	7.5	1.8; 2.1: 4.1; 6.5	1956	North American Aviation
Fast Breeder (FBR)	300	100	45; 9: 4.5; —	1960	Detroit Edison & Power Reactor Dev. Co.
Sodium Graphite (SGR)	238	75	16.0; —: 8.3; 2.2	1959	CPPD of Nebraska; Atomics Int'l (NAA)
Pressurized Water	500	134	34.5; —: —; 5	1959	Yankee Atomic Electric, Westinghouse, Stone & Webster
Organic Moderated (OMRE)	16	0	—; 0.7: 0.8; 0.4	1957	Atomics International (NAA)
Small-scale jointly-financed projects (second round, power demonstration program)§					
Sodium-D_2O (SDR)	—	10	7.4	1961	Chugach Electric, Anchorage, Alaska; NDA
Closed-cycle N_2-cooled	—	15	6.4	1960	City of Holyoke, Mass.; Ford Instrument Co.
LMFR	—	25–40	23.6	1960	City of Orlando; Fla.; —
OMR	—	12.5	5.3	1960	City of Piqua, Ohio; Atomics International
BWR	—	22	6.2	1960	RCPA, Elk River, Minn.; AMF Atomics
PWR	—	2	1.6	1959	Univ. of Florida; Alco
Aqueous homogeneous	—	10	3.6	1959	Wolverine Electric, Hersey, Mich.; Foster-Wheeler
Privately-financed projects					
Pressurized-water Th-U converter	500	140¶	55	1959	Consolidated Edison of N.Y.; Babcock & Wilcox
Dual-cycle boiling water	670	180	45	1960	Commonwealth Edison of Chicago; GE, Bechtel
Aqueous homogeneous	—	150	~50	1962	Penna. Power & Light; Westinghouse
Boiling water	—	5–10	3–4	1957	Pacific Gas & Electric; GE
Bismuth graphite (BGR)	—	200	50	1962	Florida power companies; Babcock & Wilcox, Allis-Chalmers

* Does not include research and development costs unless otherwise specified. † Capability. ‡ First two numbers are portions borne by industry; second two numbers are costs borne by AEC—in each case, figure at left is capital cost and figure on right is research and development charges. § Cost figures do not include $27-million for research and development. ¶ Plus 96 Mw added via heat from an oil-fired superheater.

preliminary stage and depend on development work now underway.

Program Developments

Five years ago, a number of feasibility and economic studies were carried out by the national laboratories, AEC, and various industrial groups to evaluate reactor systems for plutonium production and for power production. The aim was to select the most promising systems and streamline the reactor development program along these channels.

Five systems were chosen for further extensive development. These systems were: (a) boiling water, (b) pressurized water, (c) sodium graphite, (d) aqueous homogeneous, and (e) fast breeders. In April, AEC announced that it had signed a contract with

Atomics International (NAA) for the construction and operation of an organic-moderated reactor experiment (OMRE) in Idaho. This experiment is designed to establish the technical feasibility of using the hydrocarbon diphenyl as moderator and coolant. (It is interesting to note that the use of diphenyl as a coolant was proposed in 1942 for the first Pu-production reactor.)

In May, AEC announced that negotiations with Babcock & Wilcox Co. are proceeding for the construction of a liquid-metal-fueled reactor experiment. In June, the Commission announced a gas-cooled reactor with a closed-cycle gas turbine as the seventh system for its program of research and development aimed at the achievement of economic electrical power from nuclear fuels. Other types also being considered are: (a) sodium-cooled D_2O-moderated, (b) liquid-metal fast breeders, and (c) dilute-solution homogeneous U^{235} burners.

If one adds to these systems power-reactor types being developed and built in foreign countries, and reactors for submarine propulsion, there are more than 20 nuclear systems that appear to be promising for economic power production. These are listed in Table 3 according to type of moderator.

It is evident that the large number of promising power-reactor types is due more to the wide range of possible coolants than to the choice of moderator. Most thermal reactors being considered use graphite, H_2O, or D_2O for moderation. But thirteen different coolants are used in proposed systems.

Power-Reactor Nomenclature

Adam	*Swedish Power Reactor (nat. U, D_2O)*
ALPR	*Argonne Low-Power Reactor (boiling water)*
APPR	*Army Package Power Reactor (pressurized water)*
APS-1	*USSR Atomic Power Station (graphite, H_2O)*
ARE	*ORNL Aircraft-Reactor Experiment*
BGR	*Bismuth Graphite Reactor*
BORAX-3	*Boiling-Water-Reactor Experiment*
BWR	*Boiling-Water Reactor (dual-cycle)*
Calder Hall	*U. K. Dual-Purpose Reactor (graphite, CO_2)*
CDR	*CO_2 D_2O Reactor*
CGR	*CO_2 Graphite Reactor*
EBR-1, EBR-2	*Experimental Breeder Reactors (fast)*
EBWR	*Experimental Boiling Water Reactor*
EL-3	*French Enriched-U, D_2O Research Reactor*
Eve	*Swedish Power Reactor (nat. U, D_2O)*
FBR	*Fast Breeder Reactor*
G-1, G-2	*French Power Reactors (air, graphite; CO_2, graphite)*
HR	*Homogeneous Reactor*
HRE	*Homogeneous-Reactor Experiment (UO_2SO_4, H_2O)*
HRT	*Homogeneous-Reactor Test (UO_2SO_4, D_2O)*
LAMPRE	*Los Alamos Molten-Pu-Alloy Reactor Experiment*
LAPRE-1, LAPRE-2	*Los Alamos Power-Reactor Experiments ($UO_2H_3PO_4$)*
LMFR	*Liquid-Metal-Fueled Reactor (U + Bi)*
LSR	*Large Ship Reactor (pressurized H_2O)*
NPD	*Canadian Nuclear Power Demonstration (U + D_2O)*
OMRE	*Organic-Moderated-Reactor Experiment (diphenyl)*
PAR	*Pennsylvania Advanced Reactor (aqueous homogeneous)*
PWGR	*Pressurized Water Graphite Reactor*
PWR	*Pressurized Water Reactor*
R-3a, R-3b	*Sweden Power Reactors (nat. U, D_2O)*
SAR	*Submarine Advanced Reactor (pressurized H_2O)*
SDR	*Sodium D_2O Reactor*
SFR	*Submarine Fleet Reactor*
SGR	*Sodium Graphite Reactor*
SIR-A, SIR-B	*Submarine Intermediate Reactors*
SRE	*Sodium Reactor Experiment (Na, graphite)*
STR-1, STR-2	*Submarine Thermal Reactors (pressurized H_2O)*

If these coolants are arranged in order of increased difficulty of handling and other problems, this same order is roughly representative of the technical feasibility of the various types of reactors. Thus, the solution of problems associated with the various coolants is necessary to the success of a given type of reactor. The list of coolants arranged in order of difficulty of handling is given in Table 4, along with the types of reactors associated with each coolant. At the risk of criticism from those developing coolants near the bottom of the list, the estimated dates of established technical feasibility are also shown. These dates are based on operation dates of engineering-test prototypes or larger-scale reactors.

The performance of each coolant and associated reactor type, measured in terms of heat-removal possibilities and corresponding economic advantages, is in many cases inversely proportional to technical feasibility. In other words, as one goes down the list, problems become more difficult, but prospects for low-cost power increase.

Technical Developments

A number of technical "breakthroughs" have been made that improve the economic feasibility of various reactor types.

H_2O reactors. Highly enriched reactors using ordinary water as the coolant and moderator have emerged as a most promising type for small plants and transportable (package) reactors. The advantage of this system is due mainly to the compactness of H_2O-moderated cores and the relative simplicity of H_2O-cooling and -steam-generation systems. The main problem is the design of fuel elements and the difficulty of obtaining long burnup cycles.

Fuel elements. Fuel-element designs in existing reactors are almost exclusively of the MTR type, that is, slightly curved plates mounted in a rectangular-box subassembly. For high-temperature operation, the aluminum cladding used in the MTR must be replaced with either Zircaloy-2 or stainless steel, and the uranium-aluminum fuel alloy replaced with either an alloy or an oxide dispersion of uranium in Zircaloy-2 or stainless steel. Fabrication costs of such fuel elements, combined with relatively

The Research-Reactor Picture

Graphite piles. *These have been the "work horses" of the isotope-production industry. There has been a trend away from these reactors in recent years because of their inherently high cost and the difficulty of obtaining high neutron fluxes. Only one of these reactors, the Belgium Research Reactor at Mol, has been built since 1950. However, an uncooled graphite exponential pile, fueled with natural-uranium rods, is an excellent, safe, and economical student-training device.*

D_2O reactors. *Natural-uranium-fueled-D_2O-moderated reactors have found particular favor in countries that wish to be independent of the availability of enriched uranium. In these reactors, high neutron fluxes can be obtained, but at a cost somewhat higher per unit of flux than in the research reactors fueled with enriched uranium (8). Thus, the construction of these reactors has been limited; since 1950 only five have been built or planned, all outside the U. S.*

The advantage of using enriched fuels to obtain high thermal-neutron fluxes at relatively low cost is now generally accepted and 90% of all research reactors built or planned since 1950 use enriched fuel.

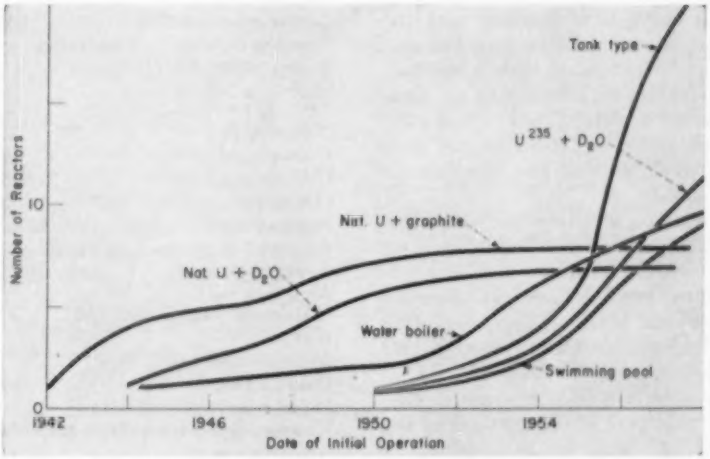
H_2O vs. D_2O. *The controversy concerning the relative merits of light-water and heavy-water U^{235} fueled reactors has existed for a number of years. On the basis of numbers of reactors built or planned, the proponents of light-water reactors seem to have the upper hand. But there is no evidence that reactors of the CP-5 or Dido type will not continue to play an important role in research-reactor programs. Because of the availability and relatively low cost of D_2O at the present time, it is possible that more groups will select this reactor type. Because of the need for research reactors with the smallest fuel loading, foreign countries may favor low-flux D_2O-moderated systems.*

Swimming-pool and tank-type reactors. *Swimming-pool and tank-type reactors are here distinguished by those that operate at power levels below 200 kw, and thus require no forced cooling, and those that require such a system. It is not certain that 200 kw is the proper power level at which to make such a distinction, but open swimming-pool reactors normally do not operate above 100–200 kw. Above this point, there is likely to be a radiation problem due to the N^{16} activity of the water. Although a forced-circulation cooling system is not necessary at even 1,000 kw for temporary heat removal, a small cooling system normally is used above 200 kw for continuous cooling and to keep the N^{16} activity away from personnel.*

Through usage, the term "swimming pool" has been applied to many reactors that are really tank-type reactors rather than open pools. Disregarding these differences, 32 reactors of the H_2O U^{235} + Al-plate-type fuel-element variety will be operating in the not-too-distant future, with the majority striving for the higher fluxes obtainable in a tank-type reactor with a forced-cooling system.

Water-boiler reactors. *Units of this type, fueled with a light-water solution of U^{235} as sulfate or nitrate, seemed a few years back to be promising competitors to the swimming-pool and tank-type reactors. Recent indications are that water boilers will find only limited use as research reactors. There are two reasons for this. First, water boilers can not operate at average neutron fluxes above 3×10^{12} n/cm² sec, unless the system is pressurized so that the uranium-solution temperature can be raised above 100° C. This is because at these fluxes at temperatures lower than 100° C, the uranium precipitates as peroxide even when the solution contains an iron and copper catalyst (5). The second problem likely to be encountered in water boiler reactors is that of possible corrosion of the reactor tank and subsequent leakage of the highly radioactive uranium solution. Both of these difficulties have been encountered in the North Carolina State College Reactor, which has been out of operation more than a year waiting for a replacement tank (9).*

Operation of an aqueous-solution reactor, even a water boiler, requires very highly trained technical personnel, experienced and familiar with the chemical and nuclear characteristics of such a system. Because of this, the use of water boilers will find only limited application. My recommendation to those planning to build and operate water boilers—"Have plenty of chemists!"



WORLD RESEARCH-REACTOR construction trends. In addition to the reactors shown, there soon will be two graphite research reactors using enriched uranium—a Russian reactor and the modified BNL pile

short burnup cycles, result in fuel costs of about 20 mills/kwh or greater. Thus, reactors using these fuel elements probably will not be applicable for civilian power plants.

Fuel-element development work to simplify fabrication and increase operating cycles is in progress, with the trend toward tubular fuel elements filled with unbonded, slightly enriched, UO_2 compressed pellets, with the tubes mounted in a typical box subassembly. Considerable reductions in fuel costs will result if these fuel elements are successful.

Improving aluminum corrosion resistance. Tests on the improvement of the corrosion resistance of aluminum to high-purity water have been underway for several years. This is important to the development of water-moderated power reactors in that the use of aluminum as a cladding material offers the possibility of greatly reduced fuel costs. Commercial 28 aluminum is reasonably resistant to water corrosion; however, most aluminum alloys oxidize and disintegrate rapidly at temperatures of 250–275° C, necessary for power production.

An alloy-development program at Argonne National Laboratory has indicated that additions of nickel up to 1% or so, and other materials such as copper and titanium in small amounts, markedly reduce the tendency for 28 aluminum to disintegrate. Tests at temperatures of about 290° C indicate corrosion rates of less than 2 mils/yr with 28 Al + 0.9% Ni, Al + 1% Ni, 0.2% Ti, and Al + 1% Ni, 0.3% Fe, 0.15% Mn in contact with distilled water. With 28 Al + 0.9% Ni in contact with acidified water (H_2SO_4, $pH = 3.5$) at 290° C, the measured corrosion rate was 1 mil/yr. Limited tests under irradiation indicate lower corrosion rates than obtainable in loop tests. The presence of hydrogen results in low corrosion rates.

Casting fuel elements. Another fuel-element development program is being carried on at Argonne in connection with the fast-breeder program. A method of uranium casting of rods in precision molds is being perfected to develop a fuel element that can be made by completely remote operations. Tests indicate that 100 or more such elements can be cast in one operation.

D_2O reactors. With regard to D_2O-moderated reactors, the most significant development is the increased availability of heavy water at the relatively low cost of $28/lb. At this price, power costs due to D_2O inventories and losses in well-designed reactors are very low. Thus, the additional neutron economy obtainable with D_2O can be exploited much better.

Aqueous homogeneous reactors. Aqueous-homogeneous reactors have long been plagued with the problem of separating and recombining the gases produced in the reactor from the radiation-induced decomposition of water. In the HRE, for example, at 1,000 kw and 1,000 psi operation, gas was formed at a rate of 10.3 ft^3/min at STP. A method of controlling this gas production through the use of solution catalysts has been announced recently (*4*). The addition of about 0.05 moles of copper

TABLE 3—Power Reactor Types

Reactor designation	*Designers*
H_2O moderated	
Submarine thermal (STR)	ANL, Westinghouse, G.E.
Army package power (APPR)	ORNL, Alco
Pressurized water (PWR)	Westinghouse, Yankee Atomic
Pressurized water Th-U converter	Babcock & Wilcox
Boiling water (EBWR, etc.)	ANL, AMF, G.E., Norway
Dual-cycle boiling water	General Electric
Aqueous U^{235} burner (HRE)	ORNL
D_2O moderated	
H_2O cooled (NRX)	Canada
D_2O cooled (NPD)	Canadian General Electric
CO_2 cooled	USSR, Sweden
Sodium cooled	NDA, Foster Wheeler
Aqueous homogeneous (HRT, etc.)	ORNL, Westinghouse, Los Alamos
Graphite moderated	
Air cooled (G-1)	France
CO_2 cooled (Calder Hall, G-2)	England, France
H_2O cooled	GE (Hanford), USSR
Sodium cooled (SRE, SGR)	NAA
Bismuth cooled	B & W, Florida power groups
Liquid-metal fueled (LFMR)	B & W, BNL
Nitrogen-cooled closed-cycle gas turbine*	Ford Instrument
Organic moderated	
Diphenyl cooled (OMRE)	NAA
Beryllium moderated	
Submarine intermediate	GE (KAPL)
Unmoderated	
Fast power breeder	ANL, APDA, Los Alamos, Britain
Molten plutonium alloy	Los Alamos

* Other moderators being considered.

TABLE 4—Technical Feasibility of Power-Reactor Types

Coolant	*Moderator*	*Reactor type*	*Estimated date of established technical feasibility*
Air	Graphite	G-1	1955
CO_2	Graphite	Calder Hall	1956
H_2O	Graphite, H_2O	APS-1, PWR, STR	1955–57
D_2O	D_2O	BWR, NPD	1955–56
Dilute UO_2SO_4 sol'n.	H_2O	HRE	1956
Na	Graphite	SRE	1956
NaK, Na	None	EBR	1958
Conc. UO_2SO_4 sol'n.	D_2O	HRT	1956
ThO_2 slurries	D_2O	TBR	1960
Bi, U + Bi	Graphite	LMFR	1959
Diphenyl	Diphenyl	OMRE	1957
Phosphoric acid	H_2O	LAPRE-I	1956
Molten Pu alloy	None	LAMPRE	1960

sulfate to the HRE was found to completely suppress gas production at these operating conditions. This corresponds to a molar ratio of Cu/U of about 0.3. One-third of this copper concentration is sufficient to recombine 50% of the gas. The use of copper in solution also is effective in preventing high peroxide concentrations that may lead to precipitation of the uranium from solution (*5*). For example, at 100° C power densities above 0.5 kw/l cause precipitation without copper. With copper and iron, power densities of about 10 kw/l can be reached without precipitation occurring.

Slurry handling. The other homogeneous-reactor development problem receiving considerable attention in the laboratories is that of slurry handling. Solution of this problem is necessary, since the use of slurries is essential to most types of homogeneous reactors.

The major difficulties with uranium and thorium oxides have been found to arise from settling and caking rather than corrosion and erosion. With regard to this latter aspect, a stainless-steel high-pressure loop was operated 15,000 hr with uranium- and thorium-oxide suspensions without encountering excessive corrosion rates. However, in a second loop, severe caking of thorium oxide occurred after a few hundred hours. This cake had to be removed with a chisel. Research on cake formation continues; however, the same loop has been operated subsequently for more than 2,000 hr with 1,000 gm/l ThO_2 at 300° C and 2,000 psi without encountering cake formation. It is believed that continuity of operation is possible through more careful control of slurry preparation and loop operating temperatures. A full-scale mockup of the HRT slurry-blanket system is just now starting to operate with slurry to obtain further information on the behavior of ThO_2 suspensions.

Graphite reactors. Technical developments in graphite-moderated reactors are mostly related to the heat-transfer and -removal problem in an attempt to improve the performance of this type of reactor. The good performance of the Calder Hall reactors and the advanced U. K. Civil Stage-1 reactors is, for the most part, due to the development of a unique finned-tube fuel element that gives high heat transfer, even with CO_2 as the coolant.

Reactors with gas turbines. Interest in a closed-cycle gas-turbine nuclear plant is increasing because of the advantages of such a system as a mobile or transportable unit. In such a gas-turbine plant, gases heated by the reactor are expanded directly through the turbine. Advantages include low weight and size for the power produced and high thermal efficiencies. Disadvantages are due to the poor heat-transfer and heat-transport characteristics of gas as a coolant. These disadvantages, which normally lead to higher capital costs and higher fuel costs, may be offset by the high thermal efficiencies or may be relatively unimportant for particular applications. The Army is especially interested in gas-turbine plants for remote uses because of their portability and suitability for arid locations.

Organic-moderated reactors. Plans to go ahead with the organic-moderated-reactor experiment are indicative of the success of laboratory and inpile experiments with radiation decomposition of diphenyl and terphenyl. The use of organic compounds such as these has several potential advantages, among which are low induced radioactivity, low corrosion of fuel elements, and low vapor pressures, which make reasonably high-temperature systems possible.

These advantages combine to ease the containment problem to the point where normal power-plant-type construction may be adequate, rather than pressuretight spheres or underground tanks.

Liquid-metal-fuel reactors. The liquid-metal-fueled reactor concept is another high-temperature low-pressure system that shows increasing promise of low-cost power. The inherent difficulties associated with a bismuth-cooled system, such as low uranium and thorium solubilities, mass-transfer problems, and fission-product removal, which a few years ago made this system less attractive than others, now appear to have been essentially solved by the research and development program at Brookhaven. Loops have been operated at conditions closely simulating those in a reactor for 3 yr under varying conditions with only small mass-transfer depositions being encountered (*6*). Complete removal of the oxygen from the bismuth and use of zirconium as an inhibitor have been found to aid in this regard. A low-flux fission-product-removal loop operated in the Brookhaven pile indicates the feasibility of the K-Na-Mg chloride fused-salt-extraction process for fission-product removal from bismuth.

Power Costs

So much has been said and written concerning nuclear-power economics, that most people are at present adequately confused about the prospects for low-cost nuclear power. In general, it can be said that no single reactor type has yet emerged as the most promising system for the production of low-cost power. At the present time, both the capital costs of nuclear plants and nuclear-fuel costs are high compared to conventional plants. This is shown in Fig. 1, in which the capital costs of all existing or planned U. S. nuclear plants are compared with coal-fired plants and diesel plants (*7*). Costs of prototype and test reactors are included although it is realized that the experimental nature of such reactors normally results in unusually high costs. It is evident that the difference in initial plant cost is much greater for the small plants than for the very large.

Corresponding power costs are compared in Fig. 2. Here again, nuclear-power costs are high compared to conventional power costs. However, there is some evidence that nuclear-power costs are on their way down and, in some cases, projected costs are competitive with power costs from coal-fired plants.

* * *

This article is based on a paper presented before the second annual meeting of the American Nuclear Society, June 6–8, 1956, Chicago, Illinois.

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Power and Research Reactors Move Into Hardware Stage

Descriptions of progress made on major reactor types show the speedily advancing stages of projects designed to resolve uncertainties and to perfect reactor types. This is NUCLEONICS' report on the reactor-status sessions of the annual meeting of the American Nuclear Society, held June 6-8 in Chicago.

power reactor experiments*

borax-3

Experience gained in operating the Boiling Reactor Experiment No. 3 at the National Reactor Testing Station in Idaho was described by W. H. Zinn. Radioactivity-carryover tests were described in a paper by A. J. Shor, H. T. Ward, D. Miller, and W. A. Rodger of Argonne National Laboratory.

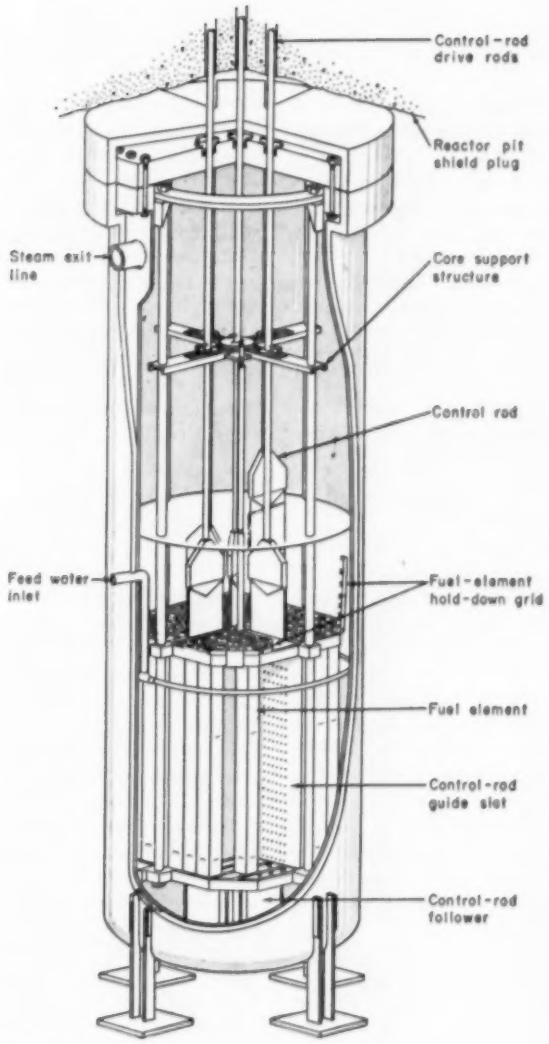
In operation since June, 1955, the Borax-3 reactor has yielded useful data on reactor and condensate water qualities, gas dissociation, stability, and radioactivity carryover for reactors whose core heat boils water whose steam goes directly to the turbine (NU, Sept. '55, p. 41).

The plate-type fuel elements, which are made of 28 aluminum (not nickel stabilized), served remarkably well in 215° C water for over 1,000 hr. Only after that time did careful tests indicate the possible presence of some fission products in the water, whose *p*H was over 7 for much of the time. The aluminum jackets are 20 mils thick; the plates are of short span (~1¾ in.) so as to be strong enough to withstand the forces arising from steam formation between the plates.

Stability. If load demand drops, the exit steam line is closed, reactor pressure rises and steam bubbles collapse—adding reactivity; by similar pressure-density effects, turbine-load increases tend to decrease reactivity. But the reactor's response to turbine load changes is slow enough for the reactor operator to adjust the control rods to counteract these inverse effects.

Startup. In placing this experimental unit in operation in a commercial system, the reactor is operated first at 1 MW to heat the water; pressure builds up. The reactor operates as any solid-water reactor does. Towards the end of the heating cycle, the power is raised to 2 Mw. At just under 2 Mw, boiling begins and power shows some roughness and fluctuates 10–15%. When the pressure gets to the operating level of 300 psi, a valve is opened so that steam enters the turbine to warm it. As the valve is opened, core pressure drops, bubbles

* The Pressurized-Water Reactor status as described by H. A. Bethel of Westinghouse was reported on last month (NU, July '56, p. R10).



BORAX-3 reactor cutaway

get larger, and reactivity decreases. This is easily counteracted by pulling the control rods; the reactor returns to 2 Mw. After turbine warmup is completed, the reactor is brought to 14 Mw, the generator develops 2 Mw, and steam pressure remains reasonably constant.

A plot of steam pressure and temperature (~430° F) over a 24-hr period at full-power operation shows satisfactory stability.

Control of water level in the reactor vessel is important in maintaining steady operation. A single pump control used on the valve controlling the feedwater inlet is quite adequate to keep 2 ft of water above the core. Except for a band control (open and close at two ends of a set band) on the backpressure regulating valves, no special features are necessary on the steam system to get satisfactory operation.

Sudden shutdown. Scramming the reactor stops steam production and the turbine valve can be closed. Afterheat tends to raise the pressure in the reactor vessel, but steam and heat losses from the system usually counteract this. Still, there have been occasions when pressure rose enough that relief valves were tripped. The pressure rise is quenched easily by pumping in cold make-up water, in which case pressure drops rather quickly and, with the added water, temperature is not likely to rise significantly thereafter.

Gas evolution. Evolution rates of gas represent a broad range of 75–200 cm^3 of gas per liter of condensed steam (25–80 ppm of oxygen in the steam); this is about twenty times the amount expected from a nonboiling water reactor. There is some belief that the excess steam formation results from the sweeping action of the steam. There appears to be a correlation of the amount of gas liberated to the *p*H of the water; the amount seemed to increase as the water got more acidic (*p*H decreased).

Radioactivity carryover. Radioactivity measurements were made on reactor water, steam samples, and turbine condensate with Borax-3 operating at 300 psig at powers of 4 to 14 Mw (power densities about 9–32 kw/liter). These tests, together with laboratory data, indicate that carryover may be less than generally supposed for the power densities and steam velocities of interest.

Decontamination factors (the ratio of beta-gamma activity in the reactor water to that in the steam or condensate) in samples permitted to decay for 24 hr vary with power level—ranging from about 5×10^3 at 14 Mw to about 2×10^4 at 4 Mw. Data on steam and condensate agree well, suggesting that at least short-lived activity does not tend to deposit in the external circuit.

Tests using tracers in small-scale equipment at pressures of 0–4 psig and in a larger 150–600-psig boiling loop suggest decontamination factors of 10^4–10^5.

Water quality. The most interesting and important technical problem faced during early operation of Borax-3 concerned means to control water quality within a reasonable range. Exchange columns proved entirely feasible for this.

The circuit used for reactor-water cleanup cools it to 100° F or less, filters it through a 10-micron cartridge, and passes it through ion-exchange columns. Strong anion or strong cation resins are always used; either one or two separate exchange columns in parallel could be used in the cycle.

In the early operations, the reactor water contained boric acid for control purposes. When enough burnup and fission-product buildup had occurred, boron was no longer needed.

Mixed-bed resins were used to remove all types of ionic contaminants so as to maintain a high water quality.

Strong anion resins are completely satisfactory for removing boric acid, but operation of anion and mixed-bed resin columns increased *p*H to about 7–8. This caused concern because of the aluminum cladding on the fuel.

The water did reach a reasonable level of purity with specific resistivity of 500,000 ohm.

The second attempt at water-quality control used separate anion and cation columns. The cation column lowered *p*H to about 5–6, which is nearly optimum for aluminum. The water was controlled to a *p*H as low as 5, but water quality dropped so that specific resistivity was 150,000 ohm. Raising flow rates through the anion column increased specific resistivity to 450,000 ohm with *p*H just over 6.

In a third series of tests, use of a mixed-bed resin column yielded 900,000 ohms with *p*H = 6.6.

The Borax-3 system included a condenser that apparently leaked significantly; thus water-quality control needs further investigation.

Boric acid as a shim. When Borax-3 was first loaded to a satisfactory condition for operation, it was critical even with all control rods inserted. This condition was corrected by adding boric acid to the reactor water. Although this was a practical way of solving the problem for the experimental reactor, it is not particularly suitable for routine operation because of the need for bookkeeping to know how much boric acid is present. Boric acid would be a suitable shim if an instrument were developed to measure its concentration continuously and accurately. Boric-acid addition proved a highly desirable scramming method.

To lengthen core life, special boron plates were welded onto fuel boxes. Plates can be pried off as more reactivity is needed.

ebwr

Status of the Experimental Boiling-Water Reactor at ANL was described by J. M. West, Argonne National Laboratory.

Under construction for about 1 yr at ANL, the EBWR plant is one-half to two-thirds completed. Startup is expected early in 1957. Core and control components are being fabricated by ANL; other fabrication and construction is being done by subcontractors. A small-scale plant, it uses a boiling-water reactor developing 20 Mw to form 600-psi steam that goes to the turbine to generate 5 Mw.

Features. Objective is to gain understanding of the operating characteristics of this type of plant so that future units can have best possible performance; thus operation of EBWR will not emphasize maximum power or steady power output. Major features to facilitate tests include:

1. Use of fuel with two different U^{235} contents (natural and 1.44%) to permit varying the critical size, power output, and power distribution.

2. Use of fuel plates with two different thicknesses will allow varying the water-to-fuel ratio. Observations will be made of how operating stability is affected by the resulting changes in power density and steam coefficient of reactivity.

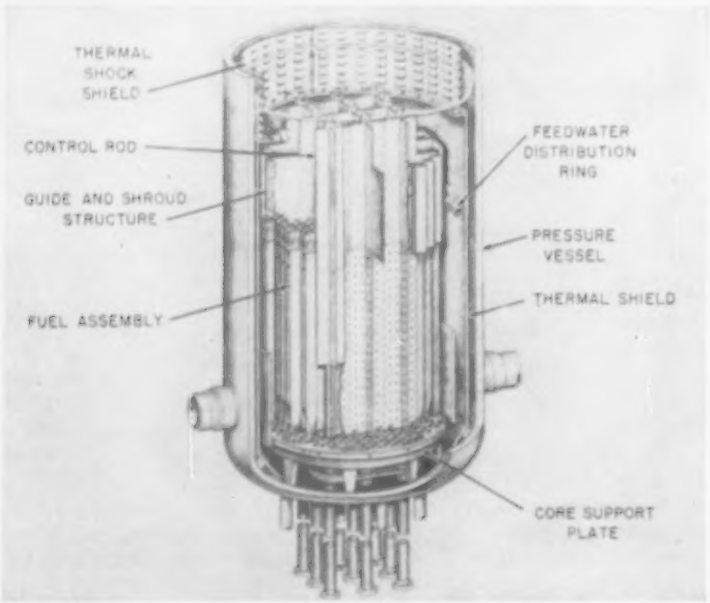
3. Initial operation will be with natural-convection cooling; subsequently, pumps and piping will be installed for forced-circulation cooling so as to learn how much power output can be improved.

4. H_2O will be used in initial operation. Later a new core will be installed and D_2O moderator substituted. This will be the first boiling D_2O reactor.

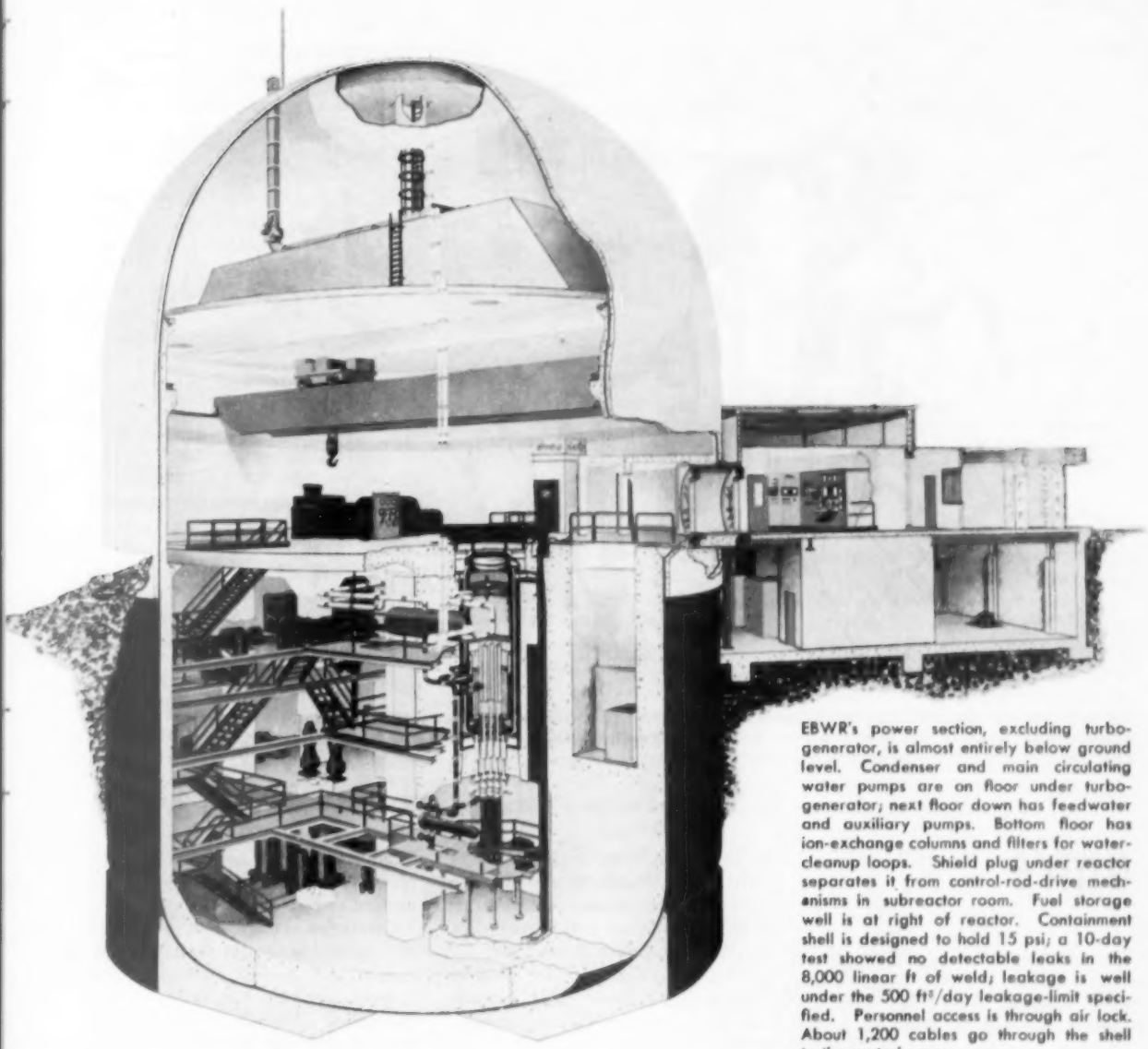
Other factors to be tested are: fuel-element integrity, corrosion and erosion, leakage (since D_2O will be used eventually), control feedback effects resulting from change in turbogenerator load, and particulate radioactivity carryover. Borax-3 data go a long way toward answering the carryover question, but EBWR will yield firmer results because of its tighter system.

The observation while operating Borax-3 that decomposition gases (hydrogen and oxygen) are present in unexpectedly high concentration in steam from the boiling reactor has caused concern about the effect of this oxygen on the turbine and other non-corrosion-resistant parts of the EBWR system. Portions of the turbine are being plated with nickel to prevent excessive oxidation of the steel.

A shield and reactor-support design has been worked out that reduces the probability that the integrity of the gastight steel enclosure around the re-



EBWR core has fuel assemblies grouped in square cells, with nine assemblies per cell. Channels between cell boxes are framed by Zircaloy in which a total of nine cross-shaped control rods move vertically. Excluding internal cladding, pressure vessel is 2¼ in. thick

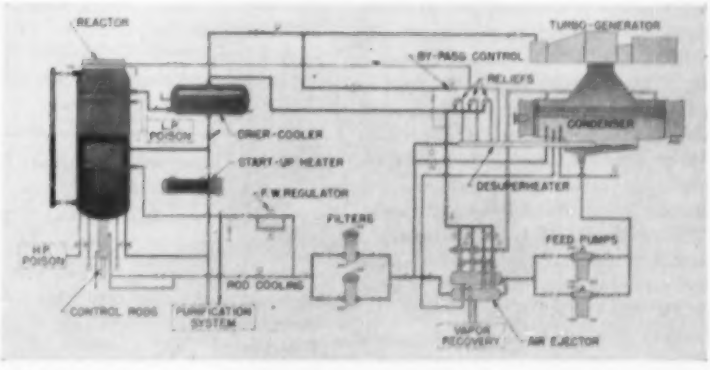


EBWR's power section, excluding turbo-generator, is almost entirely below ground level. Condenser and main circulating water pumps are on floor under turbo-generator; next floor down has feedwater and auxiliary pumps. Bottom floor has ion-exchange columns and filters for water-cleanup loops. Shield plug under reactor separates it from control-rod-drive mechanisms in subreactor room. Fuel storage well is at right of reactor. Containment shell is designed to hold 15 psi; a 10-day test showed no detectable leaks in the 8,000 linear ft of weld; leakage is well under the 500 ft^3/day leakage-limit specified. Personnel access is through air lock. About 1,200 cables go through the shell to the control room

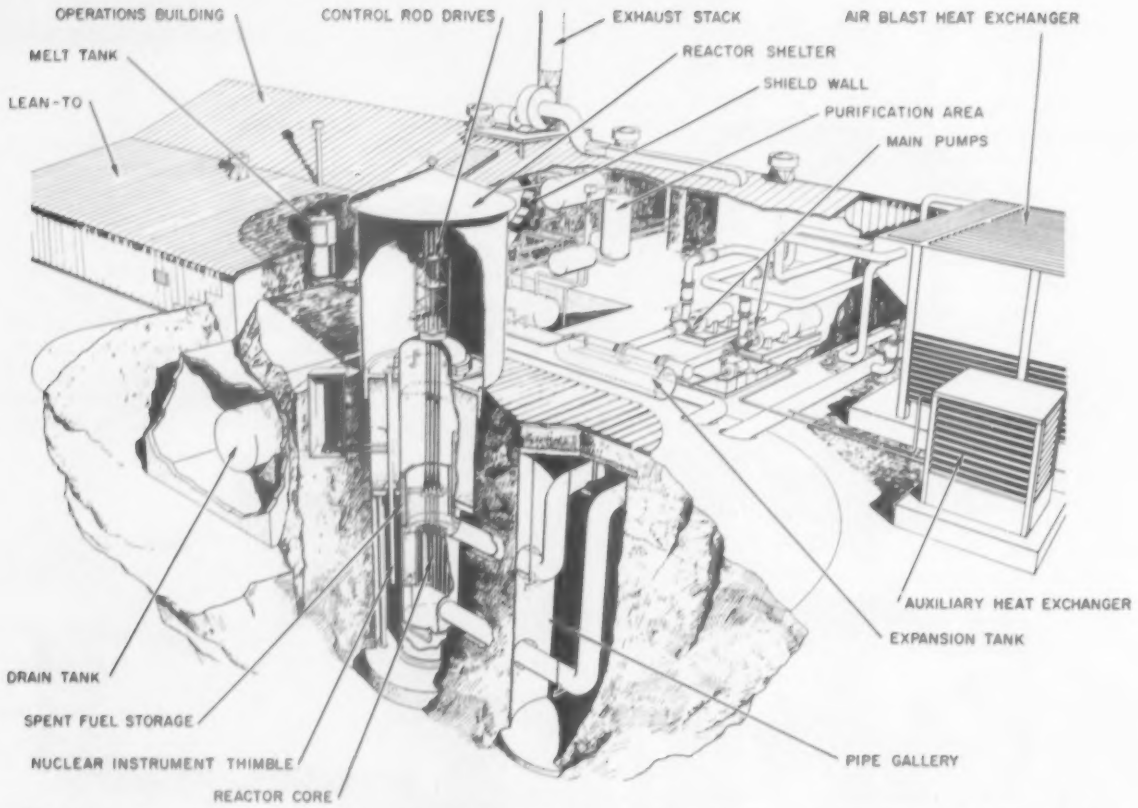
actor system can be violated by any credible reactor accident.

Fuel elements. The plate-type fuel elements are made by roll-bending and welding Zircaloy cladding to uranium-alloy meat to form plates 54 in. long, about 4½ in. wide, and about ¼ in. thick. Production of the 900 plates is well underway; about 300 are finished. Corrosion tests have shown only one failure—in the first group of 18 made.

The plates are held in assemblies whose frames and ends are of stainless steel. Six plates are in each assembly, whose total length including end sections is 79⅜ in.



EBWR flow diagram



OMRE reactor at National Reactor Testing Station in Idaho will use diphenyl as coolant-moderator and produce up to 16 Mw of heat with average heat flux of 10^5 Btu/ft²/hr (maximum flux will be three times this). Average neutron fluxes will be 5×10^{13} and 2×10^{14}, n/cm²/sec for thermal and fast neutrons, respectively

omre

Status and features of the Organic-Moderated Reactor Experiment at NRTS were explained by C. A. Trilling, Atomics International Division, North American Aviation.

Planned for operation early in 1957, this reactor is being built to test feasibility of one of the more promising hydrocarbons as moderator-coolant under conditions of actual reactor operation. It is expected to open the way for numerous applications of reactors taking advantage of the relatively low vapor pressure, negligible activation, negligible corrosion, and excellent moderating properties of hydrocarbons.

Since the OMRE is not intended as a prototype for an organic power reactor, but rather is being built to test feasibility, the OMRE program does not include any component development efforts. Generally, a power version would use equipment somewhat similar to that in water reactors. Thus, OMRE uses straightforward commercial pumps and valves—leakage is not an important factor in the experiment. Supporting engineering, research, and development studies involve work on organic inpile loops, heat transfer and fouling, purification, and physical properties.

Maximum surface temperatures of the fuel elements will be between 750 and 800° F; above 800° F thermal effects damage polyphenyls. Coolant bulk temperatures are 500–700° F—in the range of interest for power plants. Maximum coolant flow past the fuel plates will be held to 15 ft/sec so as to prevent excessive erosion.

Operation of the reactor is intended to help determine: (a) the rate of radiation and thermal damage to the hydrocarbon, (b) the effect of this damage on operation (how heat-transfer rate, flow rate, and fuel surface are affected), and (c) suitable ways to insure satisfactory operation in spite of the damage. As part of the latter work, means are being studied to purify the hydrocarbon so as to maintain a suitable steady-state concentra-

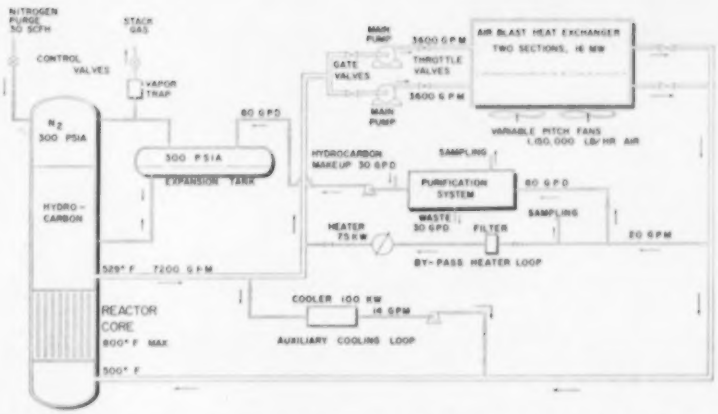
Physical Properties of Various Polyphenyls

Polyphenyl	*Melting point* (°F)	*Boiling point* (°F)	*Vapor pressure (psia)* 500° F	700° F	900° F
Diphenyl	157	492	16	110	400
O-terphenyl	135	630	3	27	132
M-terphenyl	189	689	1	16	77
P-terphenyl	416	709	1	12	60

tion of the decomposition products in the organic.

Advantages of using organic moderators are: (a) hydrogen moderation permits a small and compact core (2 × 2 × 3 ft); (b) fluid moderator adds to nuclear safety because of its high negative temperature coefficient of reactivity; (c) low vapor pressure allows use of a low-pressure system as compared to pressurized-water reactors; (d) negligible neutron-induced activation permits easy access to primary systems; (e) negligible corrosion with standard materials of construction means that special and expensive alloys are not needed; (f) lack of organic reaction with uranium assures safety in case of rupture of a fuel element; and (g) further safety comes from the fact that the organic will not react with the water in the steam system if the heat exchanger should leak.

Disadvantages of using organic moderators are: (a) lack of stability of organics in high temperatures and radiation fields; (b) low thermal conductivity causes heat-transfer problems so that high temperature differences are needed; (c) flammability and possible toxicity cause safety hazards; (d) the difficulty of physical containment leads to sealing problems; (e) because the vapor pressure is significantly above atmospheric, a pressurized system is needed; (f) high melting point means that the system must be preheated before startup; and (g) small latent heat. It is believed that each of these disadvantages can be overcome.



OMRE system uses low-carbon-steel piping and vessels. Main piping from core is of 16 in. diameter. Auxiliary cooling loop is for removing afterglow heat under emergency conditions. Core is 2 ft square and 3 ft high; 14-ft pool of diphenyl above core provides shielding; reactor vessel is 28 ft high. Circulating N_2 purges decomposition gases

Available information on radiation effects on organics is from capsule irradiations, accelerators, or inpile loops; it all indicates that polyphenyls are among the most promising of organic compounds for use in reactors.

Under irradiation, there is some decomposition, manifested by gas evolution (H_2 mostly) and formation of compounds of high molecular weight. These stay in solution in the original liquid to a fairly high concentration.

Indications are that any of the polyphenyls could be used satisfactorily. There is very little thermal decomposition up to 800° F. The thermal conductivity of water is about four or five times that of the polyphenyls, whose conductivities range from 0.06 to 0.08 Btu/hr/ft/° F—which is practically that of Superex insulation.

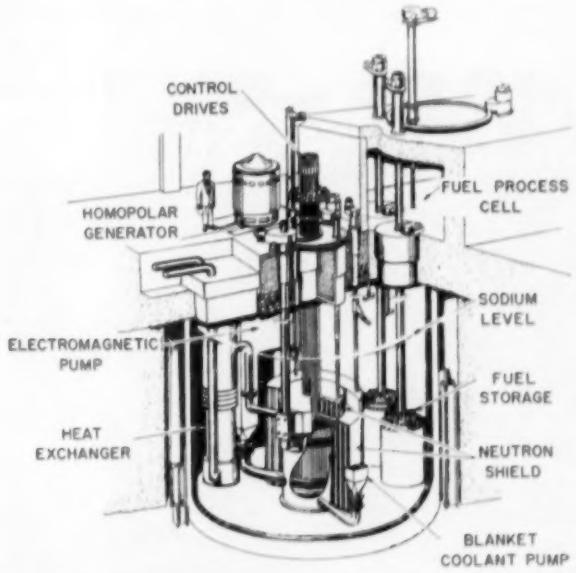
ebr-2

Features and status of the Experimental Breeder Reactor No. 2 at ANL were described by L. J. Koch, Argonne National Laboratory.

Unique among the features of EBR-2 is the contained-submerged arrangement of the reactor primary sodium cooling system (including pumps and heat exchanger) and fuel-unloading system, all parts of which are in a large tank and operate submerged in sodium. The desire for high thermal performance led to this arrangement, whose feasibility has been demonstrated by a large working model.

Fuel elements. High power density at high temperature requires finely divided fuel elements that have short paths for heat exchange.

The fuel is to be reprocessed in a

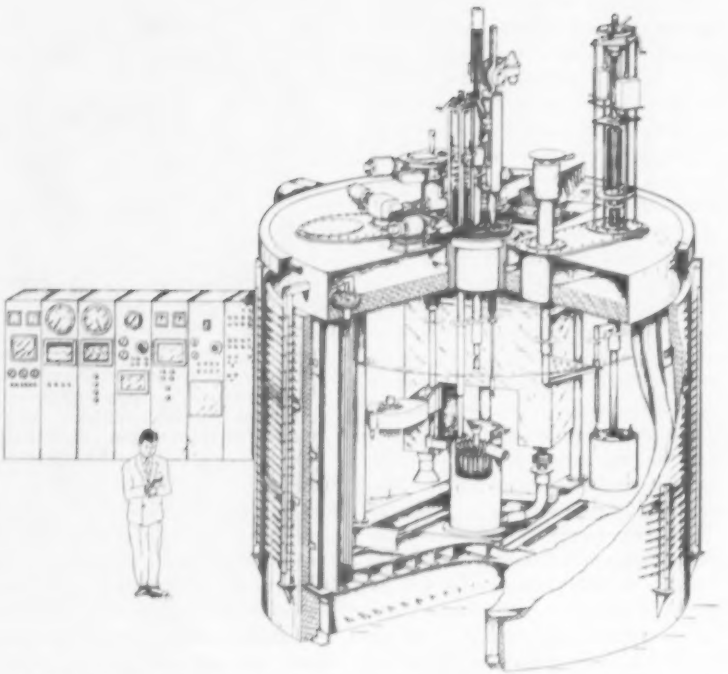


EBR-2 is a sodium-cooled fast reactor designed to produce about 60 Mw of heat that is to be used to generate 20 Mw of electricity. The sodium leaves the reactor at 900° F. About 10 Mw of heat are generated in the blanket; 50 Mw come from the 50-liter core. A high-pressure circuit cools the core and a low-pressure circuit cools the blanket. Afterheat cooling is by natural convection

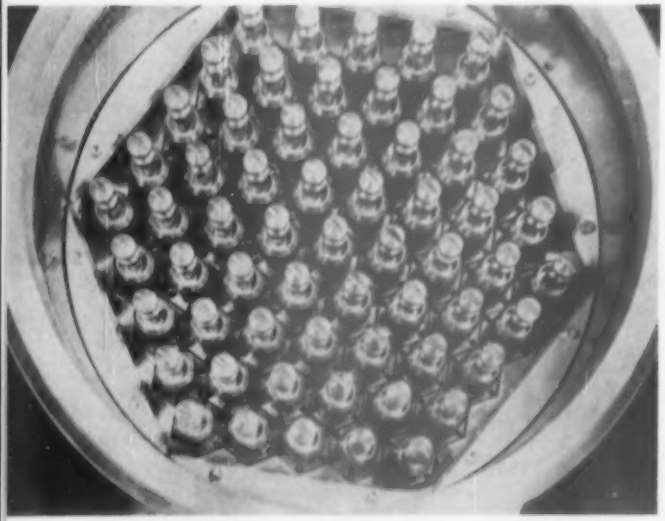
pyrometallurgical plant that is an integral part of the facility. This method of reprocessing removes enough fission products so that the fuel can be reused in the reactor, but enough remain to make the fuel sufficiently radioactive that refabrication and assembly must be done by remote control in a hot-lab-type facility. To permit this, the fuel elements must be simple and conducive to repetitive operations in fabrication.

Fuel fabrication. The empty tube will be fabricated and the sodium for the bond will be put in the tube as a solid extruded to proper size to give the needed volume in the assembly. Then the unit will be sent to the refabrication plant. A shielded cell will be used for subsequent operations in completing assembly of the fuel elements.

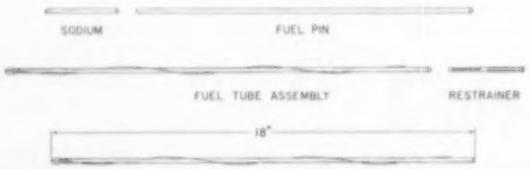
The fuel alloy pin is precision cast to the proper size by a pressurizing technique into an expendable mold. It is then cut to the appropriate length and delivered to the assembly station. The fuel pin is inserted in the tube, the top closure is inserted, and the final weld closure is made at the top end by an automatic cone-arc procedure. The hook at the lower end is part of the bottom closure.



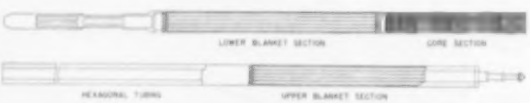
EBR-2 WORKING MODEL, operating since August of last year, has shown practicality of contained-submerged arrangement of reactor primary system. With dummy reactor and valves, instruments, 1,000 gpm pump, and other components in a 10-ft-diam vessel, isothermal operation was conducted with sodium heated electrically to 750° F. It is believed to be the largest sodium system of its kind to be operated in this manner



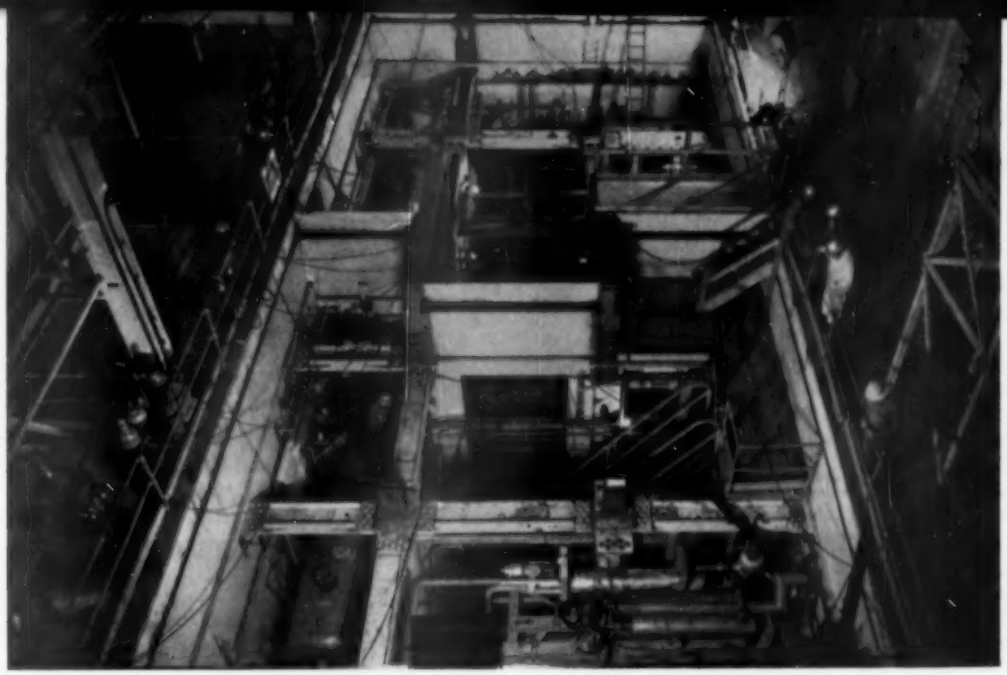
EBR-2 reactor in working model shows dummy fuel assemblies as seen from above



EBR-2 basic fuel element, of which about 4,500 will be required per core loading, is a pin of about $\frac{3}{16}$ in. diameter. It consists of thin-wall stainless-steel tube; the annulus between fuel pin and tube is filled with sodium to maintain a heat-transfer conduction path. Tube has wire spiraled around outside to space adjacent pins and thereby determine coolant flow passage



EBR-2 fuel subassemblies each have cluster of 91 fuel-element pins. Assemblies are mounted vertically in reactor, with core section in center. Present plans do not include re-use of irradiated natural or depleted uranium in blanket sections; thus blanket sections are completely assembled before arriving at fuel assembly plant. Pyrometallurgically reprocessed fuel still contains some radioactive fission products and must be refabricated remotely



HRT over-all construction view shows how reactor tank looks without roof plugs. System is housed in below-grade cell that is about 25 ft deep, 30 ft wide, and 54 ft long. Core assembly is housed in small cubicle (about 9 ft across) in center. Blanket system equipment is in foreground, blanket heat exchanger is at left front; fuel system is in background

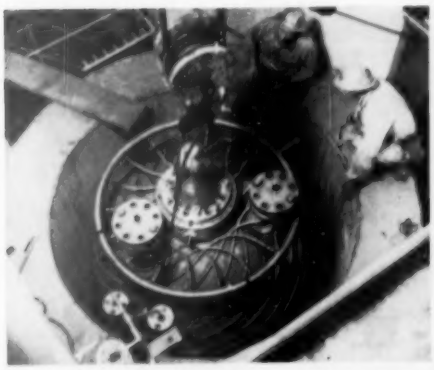
hrt

Construction and pre-startup test procedures of the Homogeneous Reactor Test at ORNL were discussed informally by S. Kaplan, Oak Ridge National Laboratory.

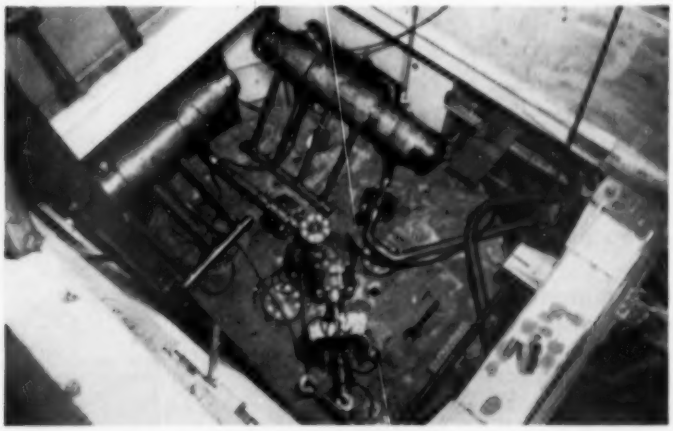
Construction of the HRT at ORNL is essentially completed and engineering tests have begun in preparation for reactor startup in late October. Heat-exchange equipment has been operated; also completed are hydrostatic pressure tests in which the high-pressure system has been held at 2,800 psi and the low-pressure system has been at 750 psi.

To operate at 5 Mw, HRT is the second major machine built by ORNL in studying the homogeneous-reactor cycle. It is larger and more versatile than HRE in that it can use several different blanket solutions; also, HRT uses a Zircaloy core rather than stainless steel, which was used in HRE.

Preliminary steps. The reactor system is being cleaned with 3% trisodium phosphate solution that is circulated hot for over 3 hr through each part of the stainless-steel piping to remove traces of grease, chloride-bearing impurities, corrosion products, and dirt. Then a solution of dilute nitric acid will



HRT core pressure-vessel assembly installed in reactor compartment. Radial tubes around pressure-vessel blast shield are for cooling. Outer tank is thermal shield, filled with circulating water. Head fits over top of compartment; mixture of steel shot and water serves as shield



HRT core compartment with top shield in place. Fuel and blanket outlet pipes and pressurizer vessels are shown. Fully assembled, four clamshell heaters will be placed over downcomers

be circulated through the whole system.

After cleansing is completed, a natural-uranium solution will be circulated through the system long enough to form a corrosion base and permit determination of corrosion rates without the complications of radiation effects. During this run, the system will be heated in reverse by blowing steam through the heat exchangers.

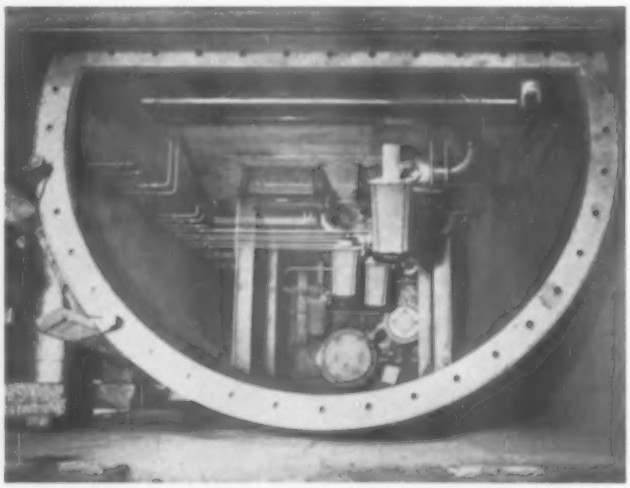
Then the whole system will be rechecked for leaktightness and a helium leaktest will be run. After this the enriched-uranium fuel solution will be put in, followed by criticality in late October.

HRT low-pressure system is shown closeup in foreground of tank

HRT reactor container with top shield assembled. Plugs are two layers thick; 3½ ft of concrete below; galvanized steel plates are sandwiched between this and 20-in. upper layer of concrete. Plates welded to steel tank form containment shell to hold 30 psi internal pressure

HRT Design Basis

Power, heat	5–10 Mw
Temp., core outlet	300° C
Pressure	$\geq$ 500 psi in excess of vapor pressure
Core diameter	32 in.
Core solution	UO_2SO_4 in D_2O
Blanket	D_2O or ThO_2 in D_2O
Fuel circulation rate	400 gpm
Blanket circulation rate	$\sim$ 240 gpm
Core flow pattern	Straight-through
Core material	Zircaloy-2
System material	Type-347 SS
Radiolytic gas removal	Pipeline separator
Radiolytic gas recombination	Low-pressure platinized alumina catalyst
Fission-product-gas disposal	Decay on activated carbon
Control:	
Normal	Variable solution concentration
Safety	Temperature coefficient



HRT instrument cubicle on north wall of reactor shield shows that primary sensing elements are isolated from reactor environs so that they can be worked on without access to reactor cubicle

lapre-1 & 2

Features and status of the Los Alamos Power-Reactor Experiments Nos. 1 and 2 were described by L. D. P. King, Los Alamos Scientific Laboratory.

Small homogeneous power reactors are being developed at Los Alamos for special purpose or portable power plants rather than for large central-station units. The aim of producing 850° F temperatures is based on the properties of solutions of highly enriched uranium and uranyl phosphate. The highly corrosive properties of these solutions dictate use of gold lining on the stainless-steel vessels. There are no worries about formation of radiolytic gases since, at the pressures used, the recombination rates are higher than the dissociation rates.

Two types of phosphate solutions are being tested in separate reactor designs known as LAPRE-1 and LAPRE-2. Both operate at 850° F and their basic nuclear designs are interchangeable.

LAPRE-1. To serve as a short-term test of its particular reactor design and solution type, LAPRE-1 went critical several months ago. However, the gold cladding was accidentally stripped off part of several tubes while they were being put into the system; the situation was not noticed at the time. Thus, a leak developed in the steam system at 300° C. With a new set of coils, the reactor is nearly ready to operate again. LAPRE-1 uses forced circulation through an internal heat exchanger and is designed to produce 2 Mw heat in a 7.5-molar phosphate solution. Single-phase steam-water system through the heat exchanger leaves at 3,600 psi and 800° F through a throttling valve steam silencer to the atmosphere. The 3-in.-steel reactor vessel is about 15 in. in diameter, and 6 ft long. Initially, it is about 60% full of fuel solution; during operation only 15% of the volume is vapor space. No fuel solution need be transferred for control purposes after this. This type of reactor can be scaled up substantially for greater power outputs.

The inside walls of the vessel are plated with 5 mils of gold; heat-exchanger tubes are clad 6 mils thick. The vessel's bolted seal is away from the high radiation field. The Allis-Chalmers sealed-rotor pump has hydraulic bearings; the pump is not gold plated since it operates below 100° C.

The control rods enter near the core, and are clad with platinum so as to decrease neutron capture. Calculations indicate that if one had a container large enough to hold the solution at operating temperatures, a gain in reactivity of about 25% would result in going to room temperature. This type of reactivity change is difficult to control with rods. With homogeneous systems, one can add solution or change concentration as desired. This method is not very attractive at high pressures with highly radioactive solutions. The LAPRE reactor is designed to eliminate this kind of solution handling and permit retention of the solution in the reactor vessel at all temperatures.

The vessel is divided into four parts: a nonreactive storage volume at the bottom, an internal heat exchanger, the reactor proper, and a vapor volume. Cold critical is at a point about 8 in. above the heat exchanger. When the solution heats, the volume of the remainder of the reactor is such that the expansion of the solution raises its level in the core up to the proper operating level. The remaining 15% of the volume is vapor.

If power demand drops suddenly from 2 Mw to 1 Mw, power will drop while temperature will rise 1° C at complete compensation. If power demand suddenly increases from 100 watts to 1 Mw, power rises steeply, overshoots to about 8–9 Mw, drops back quickly and stabilizes in about 0.8 sec. Total temperature change is only 1 or 2° C. This shows the strong stability produced by the large negative temperature coefficients of this system.

If the cooling system or circulator fails at 1 Mw, power drops off. But temperature continues to rise unless the reactor can be shut off by inserting the control rods or removing the fuel solution. A safety disk will rupture at 7,500 psi.

LAPRE-2. Components are nearly finished for this extremely simple 1.3-Mw power-reactor experiment; it has no moving parts. Operation is scheduled for September.

With boron poison in the core and a minimum of instrumentation, the aim is to operate the reactor for 2–2.5 yr with no maintenance and no more operating attention than an ordinary small steam plant. A neutron-sensitive detector is outside the reactor vessel; it is used only for startup, thereafter control will be through measurement of pressure and temperature.

LAPRE-2 uses a more concentrated H_3PO_4 solution that operates at about 800 psi. The reactor vessel is ⅝ in. thick, has a gold cladding (rather than plating), is about 15 in. in diameter and 4 ft long, and has cooling coils. It is housed outdoors in a 20-ft cylindrical steel tank whose 42-in-diameter top is flush with the ground; the tank is located about 75–100 ft from the control building.

An auxiliary tank of 6-ft diameter and 20-ft length is connected to the reactor vessel at all times and serves as a storage and safety vessel. Initially, fuel solution is stored in this copper-lined tank. At startup, the reactor vessel is only 78% filled with fuel solution. When the temperature rises during operation, only 5–6% of the volume is vapor space. Steam is generated in an internal heat exchanger by convective flow of the fuel solution.

lmfr

Progress on the Liquid-Metal-Fuel Reactor was explained by Clarke Williams, Brookhaven National Laboratory.

A number of significant developments are bringing the LMFR concept closer to the hardware stage at BNL. The system has been judged feasible and efforts are being made to resolve remaining technical questions. Engineering design of the LMFR experiment is about to begin in cooperation with Babcock & Wilcox Co.

An exponential assembly is planned to verify the physics aspects of the design, which have had a theoretical base to date. Multigroup calculations on a UNIVAC have verified the two-

group "slide-rule-type" calculations of LMFR core size.

A neutron source is being assembled for a subcritical exponential assembly of bismuth, uranium, and graphite designed to experimentally verify the calculations. After experiments with this device, a thermally-cold critical assembly will be used to test kinetics.

Fundamental chemistry studies have yielded a better understanding of the fuel reprocessing schemes involving oxidation of fission products from fused salts. It now is felt that enough is known about the thermodynamics of systems of fused chlorides and solutions of various materials in liquid bismuth that the salt-metal components can be tailored to produce desired characteristics. This method is very flexible for processing liquid-metal-fuel systems.

Encouragement has been gotten from experiments to pin down the mechanisms of corrosion inhibition in the system. Addition of magnesium and zirconium to the bismuth solution cuts corrosion.

The magnesium has the effect of cleaning the oxygen from the bismuth, thus reducing the solubility of iron, which is a constituent of the low-chromium steel used in the vessels and piping.

The zirconium reduces mass transfer in two ways. It forms a zirconium nitride layer on the steel surface; this layer is very inert and only very little iron continues to go into solution. Zirconium also inhibits precipitation of iron from the solution in lower-temperature parts of the system. With no Zr in the solution, iron starts to crystallize out when the fluid is just slightly supersaturated. With Zr present, precipitation does not occur until the fluid is three or four times higher in supersaturation.

Of the loops operated at Brookhaven, two have been of particular significance. They have demonstrated that the system can be operated under proper temperature conditions, and that the amount of material dissolved off under these conditions is negligible. An inpile loop circulating U-Bi fuel in the BNL pile showed that the processing scheme using a salt is suitable for removing volatile fission products and those fission products in solution. It was operated at the average operating temperature expected in the LMFR experiment (500° C).

Different kinds of LMFR cores have been studied in an effort to get higher-energy fluxes. By using higher fuel concentrations than are desirable in power reactors, a desirable intermediate-energy high-flux research reactor might be built. This is an aspect of LMFR's that BNL wants to investigate.

research reactors

nru

The third Canadian research reactor, a 200-Mw, 3 × 10^{14} n/cm²/sec, natural uranium D_2O-moderated and -cooled pile, will go into operation before the end of this year, G. C. Laurence of Atomic Energy of Canada reported at the ANS meeting.

The reactor vessel with its vertical Al walls is 11 ft 6 in. dia, surrounded by a 6-in. gap containing a CO_2 atmosphere. A light-water reflector 12 in. thick outside that annulus is confined by Al walls. The thermal shield is 12 ft of steel cooled by a layer of water 0.5 in. thick near its inner surface. The biological shield is about 8 ft of heavy concrete containing ilmenite of about 3.5 specific gravity.

A large graphite thermal column, 12 ft long and increasing in steps in cross section from 8 × 8 ft at inner end to 12 × 12 ft at outer, extends through the shielding. Two rows of Bi rods across its inner end reduce the intensity of gamma radiation from the reactor in the thermal column.

Experimental facilities. Of 230 fuel rod positions, 200 will be used for fuel, the rest for control and protection, irradiation of materials, and experiments. Minimum internal diameter of the hole through the shielding above these positions is 4.75 in.; three of these holes also extend through the lower shielding to permit piping connections from both above and below. Two larger experimental holes extend through the reactor; Al tubes of elliptical section 3.25 × 4.5 in., they pass through a 2 × 10^{14} flux region. Open at both ends, they provide four intense beams of narrow cross-sections suitable for experiments where a high degree of collimation is required, such as neutron diffraction investigations.

In addition to these vertical holes, there are 23 horizontal holes; seven are 12 in. dia at the inner end, the rest 6 in. Six of the holes extend 16 in. into thimbles in the core to a 10^{14} flux region; six others are spares, terminating at the outer surface of the reflector, but extensible by thimbles into high-flux position later when the reactor vessel is replaced. The possibility of replacing the side walls of the reactor and reflector is a special feature of the design. Each experimental hole position is provided with these services: water, air at 20 and 100 psi, steam propane gas, drain, 110-v 60-cycle, 220-v 60-cycle, and 575-v 3-phase 60-cycle current.

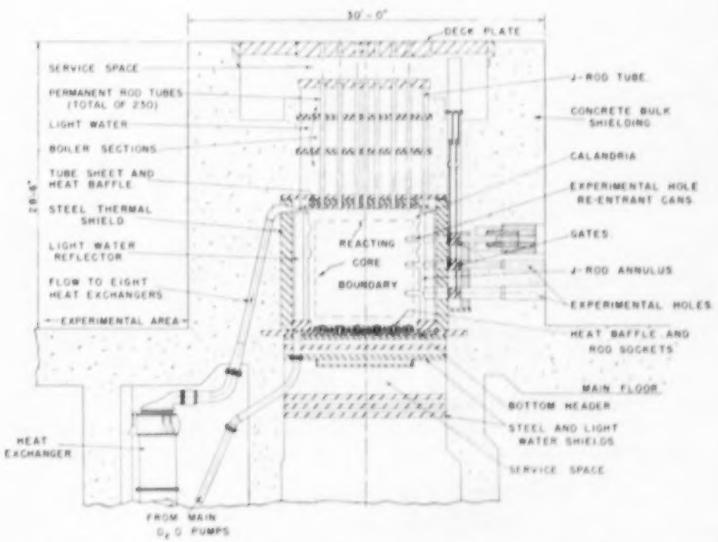
In the CO_2-filled annulus with its 2 × 10^{13} n/cm²/sec flux, provision is made for 44 vertical rods that may contain Th or material for producing radioisotopes. The positions may also be used for experimental loops. Forty positions can take rods of 2-in. outside dia, four rods of 4.5 in. A few positions may be cooled by separate circuits for special experimental purposes. Also provided are tray rods that can be loaded with materials for irradiation. Their loads can be transferred by remote control to a tube and driven through a pneumatic carrier system to a laboratory in another part

NRU under construction in 175 × 160 × 100-ft high main reactor hall at Chalk River. In center is outer shell of biological shield before insertion of reactor vessel and upper shielding. Walls of experimental rooms are seen behind reactor. In center bottom of near face, behind temporary covering, is opening of thermal column; opposite it in foreground will be storage block. Overhead is 75-ton crane

of the building; the pneumatic system can be extended to carry irradiated materials to other buildings as well.

Philosophy. In providing these experimental facilities, Atomic Energy of Canada has been guided considerably by experience with NRX, and has attempted to foresee future requirements. It has been found that the demand for loop experiments and other engineering research in reactors has been increasing rapidly, and particular attention has been given to providing space in shielded rooms and access to the reactor for such purposes.

A large storage block for shielding irradiated and active materials is located opposite the reactor in the main hall; beyond this, an area of about 25 ft² is reserved for construction later of a zero-energy reactor for use in testing the changes in the reactivity of fuel rods that have been irradiated in the main reactor.



NRU cutaway shows arrangement of core, experimental ports, thermal column, and cooling system

wtr

Drawings for the Westinghouse Test Reactor, to be built at Waltz Mill, Pennsylvania, 30 mi E of Pittsburgh, are now being completed; the reactor is scheduled to go critical in August 1957, and in November 1957 "we will have neutrons for sale," M. A. Schultz reported.

WTR exemplifies the historic trend in testing reactors toward higher power and flux levels. Designed originally for 5-Mw operation, up to 10 Mw when it was announced, it is presently slated to run at 20 Mw; but designs are already being modified to permit operation at 40 and ultimately 60 Mw. Philosophy behind WTR is to allow the maximum possible number of high-temperature, high-pressure, high-flux experiments. Core pressure is 100 psi.

Fuel elements will be 36-in.-long, round tubes that are both symmetrical, and reversible top-and-bottom for maximum burnup. A cylindrical mandril in the center will permit high irradiation of small samples. Normal loading will be 12 kg uranium, and there will be 6 to 9 control rods.

The test thimbles will be of stainless steel, and will conform to the Pennsylvania state code for fired pressure vessels. The real problem is to get good usable flux inside them without too much gamma heating. Temperature inside will be 600° F., pressure 2,000 psi, average flux 5×10^{13} n/cm²/sec. Flux depression through the 0.3-in. thimble wall will be by a factor of 3. The gamma-heating in these walls now limits WTR power to 20 Mw.

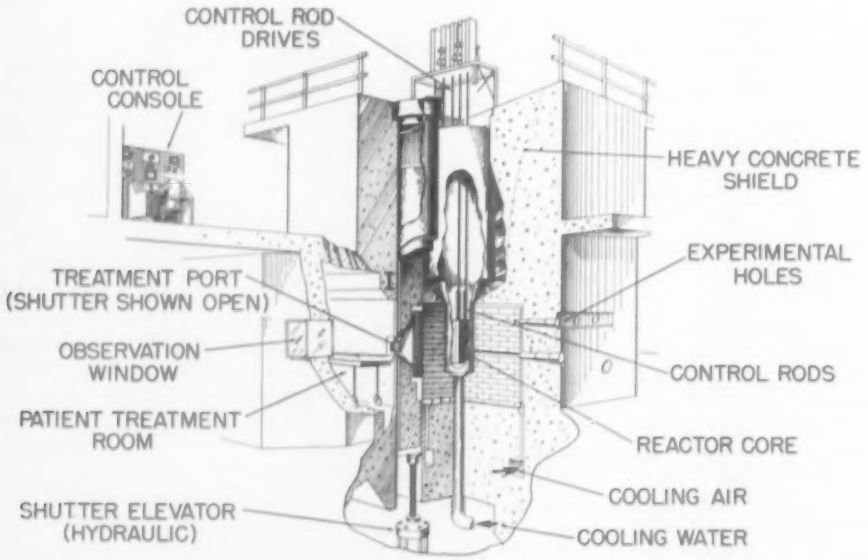
Some 5,000 in.² space will be available for sale when the reactor enters service; "price will be $\$10^{-20}$/neutron," Schultz said.

bnl-med.

Design for the new medical reactor at Brookhaven National Laboratory has been completed, and fixed cost bids have been taken for the entire job. Total cost will approach $900,000, according to Robert W. Powell of BNL.

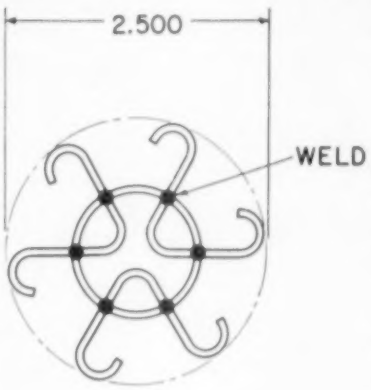
The present graphite reactor at Brookhaven has been used in many ways in the BNL medical department program, but has been found unsuitable and restricting because of these inadequacies: flux is too low, and 20–40-min treatments are needed; reactor is a mile from the hospital area, and patients must be brought to the top of the pile by freight elevator; industrial experiments in vicinity make a hospital atmosphere lacking. A survey of all available neutron sources, carried out in 1953 by NDA, showed only a reactor could deliver 10^{10}–10^{11} neutrons in a beam. After some discussion of D_2O, a light-water-moderated and -cooled, graphite-reflected type using an Oak Ridge swimming-pool type core was chosen. Power will be 1 Mw; 900 kw of heat will be removed by water cooling the core at 600 gpm flow; 100 by air cooling the reflector at 5,100 ft³/min flow. The beam strength will be 10^{11} n/cm²/sec and neutron lifetime 170 μsec. Control will be by means of one regulating rod worth 0.5% and three safety rods worth 3.5%. Critical loading will be 17 140-gm MTR-type elements, with graphite dummies filling the free spaces.

New fuel element for BNL reactor. The ANS meeting also heard a report



Brookhaven medical research reactor shows cutaway patient treatment room to left of core and large hydraulic shutter, two of which are being built by Baldwin-Lima-Hamilton Co. for $70,000

from Brookhaven on an improved fuel element design for the existing graphite reactor. Objective is to increase the neutron flux without decreasing the effective volume of the reactor; secondary goals are to simplify operation and cut operating costs. The present natural-uranium fuel element has been pushed to its limit of 500° C internal metal temperature; cooling costs now run $450,000/yr for a flux of 5×10^{12} n/cm²/sec. BNL's plan is to use in the air-cooled reactor ORNL-type Al-alloyed and -clad enriched U elements, already proven in water-cooled reactors. Each element will be 2 ft long and contain 15.3 gm uranium; heat transfer area is adjusted so that maximum metal temperature will be 350° C, and maximum graphite temperature 225° C. To achieve these temperatures with about the same mass flow of air as now used, a three-plate element was designed with each plate 3.125 in. wide, 0.060 in. thick and 2 ft long. Since the graphite channel diameter is only 2.67 in., the plates must be curled to fit; the most reasonable configuration results in a "cookie-cutter" shape (see figure). A total of 57 kg highly-enriched U (at a steady 40% burnup) will be required.



Power output will remain the same —20 Mw; but thermal flux will be increased to 2×10^{13}. Pressure loss for removing heat at the same power density will be considerably cut, permitting replacement of present fans with specially designed ones that will result in savings of $275,000/yr.

Sylvania will fabricate the first 300 elements; their work awaits AEC approval. Delivery is expected this summer.

mitr

This high-flux reactor now under construction just off the campus of the Massachusetts Institute of Technology at Cambridge, Mass., is to be completed in summer or fall of 1957, T. J. Thompson, project director, reported.

The D_2O-moderated and -cooled reactor will operate at 1 Mw as a research and teaching tool for MIT; heavy water was chosen because the design is based first on safety, since the reactor is located in the heart of downtown Cambridge at 138 Albany St. Conceptual design and specifications up to the working drawing stage were completed at MIT and sent out for bid; ACF Industries of New York was selected to complete the working design and to construct the reactor and building. AEC issued a construction permit on May 7 this year, and site preparation began in early June.

The reactor will use MTR-type 18-plate elements with 2-ft active fuel length. The core will be in a tank 4 ft dia and 7 ft high; 19 fuel elements will be arranged with one in the center, six in an inner ring and twelve in an outer ring; ten alternate positions will be available further out. Control will be by one fine regulating rod and six shim and safety rods held up by magnets; drop time is 0.4 sec. Coolant will enter at the bottom at 94° C and leave at the top at 104° during 1-Mw operation.

owr

Announced at Chicago by John Yarnell as ready to go critical within the month, Omega West Reactor at Los Alamos Scientific Laboratory has since—on July 11—been started up and is now operating at 1 Mw.

Conceived as a replacement for Los Alamos' famous fast reactor, Clementine, which failed in December 1952 (NU, Sept. '54, p. 28) and was disassembled in 1953, the new reactor is a simplified MTR built at Omega West Site in the room that had formerly housed Clementine. The need was for a reactor giving a neutron flux about one order of magnitude greater than that provided by SUPO, and having large and versatile experimental facilities. The low-power MTR design was chosen over a higher-powered water boiler because neutrons for experiments would be available much sooner without an extensive development program on water boilers; MTR had already been operating at considerably higher power than was needed at LASL, and fuel elements were already designed and obtainable from Oak Ridge.

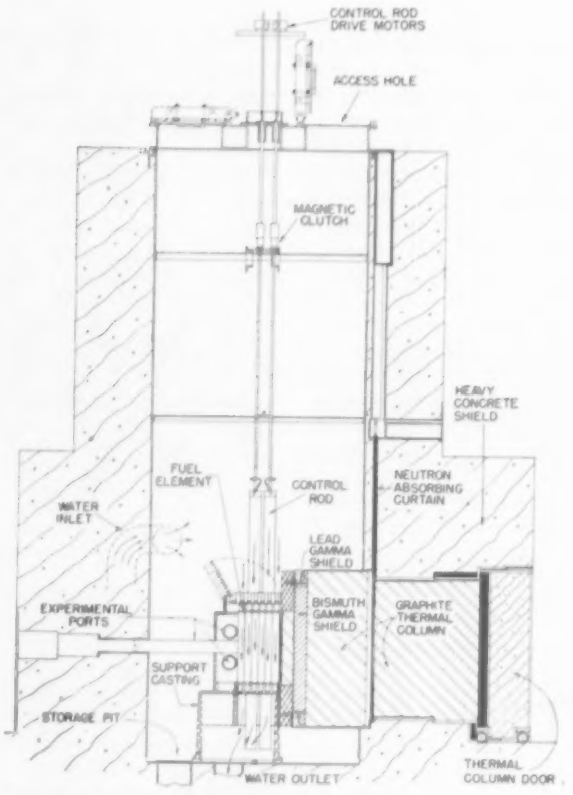
Ordinary water is used for reflector, as well as for moderator and coolant (MTR's beryllium and graphite reflectors have been eliminated). The reactor consists of a stainless steel tank 8 ft diam and 25 ft high, surrounded by 5 ft of 280-lb/ft³ concrete around the core region and 3 ft thickness at the upper half. A removable lid at the top has openings for control rod drives and for core access. The core sits on a large Al casting that also serves as a plenum for outlet cooling water.

There are 54 fuel positions, arranged in six rows by nine, which can be used for fuel elements in various arrangements, sample holders, removable reflector pieces, etc. Eight boron-loaded control rods in the form of paddles 6 in. wide by $\frac{3}{8}$ in. thick operate between fuel elements in the central four rows of fuel positions.

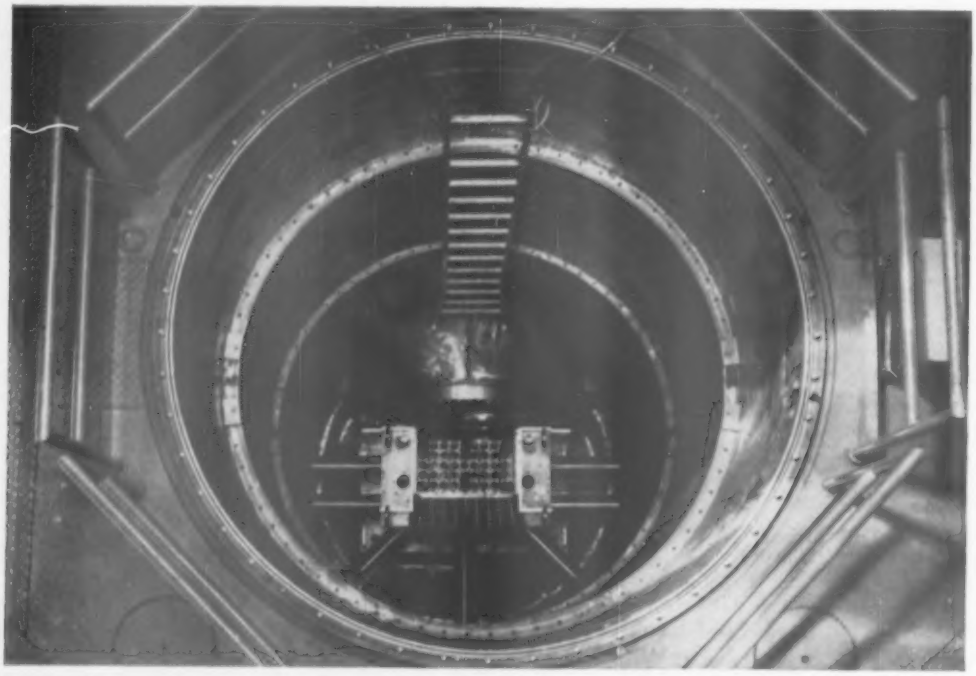
Experimental ports coming up to the core region penetrate the shield on five of OWR's six faces, and a thermal column occupies the sixth face. Gamma radiation is kept out of the thermal column by a 5-in. Bi shield

inside it; in addition, a 3-in. Pb or Bi shield will occupy the row of fuel positions next to the thermal column. Experimental ports include five 6-in.-dia end ports coming up to the core, two of them with built-in rotary shutters and sample-changing mechanisms; two 6-in. dia ports above and below the central plane that pass entirely through the reactor tangent to the core; three 12-in. throughports in the thermal column and a fourth the same size coming in from the column's end; instrument ports for control chambers extending under the core region; one providing a beam sloping up at a 30° angle from the core for experiments in which neutron scattering from the floor causes a serious background; and finally a number of specialized ports, for "rabbits" or for monitor chambers for experiments.

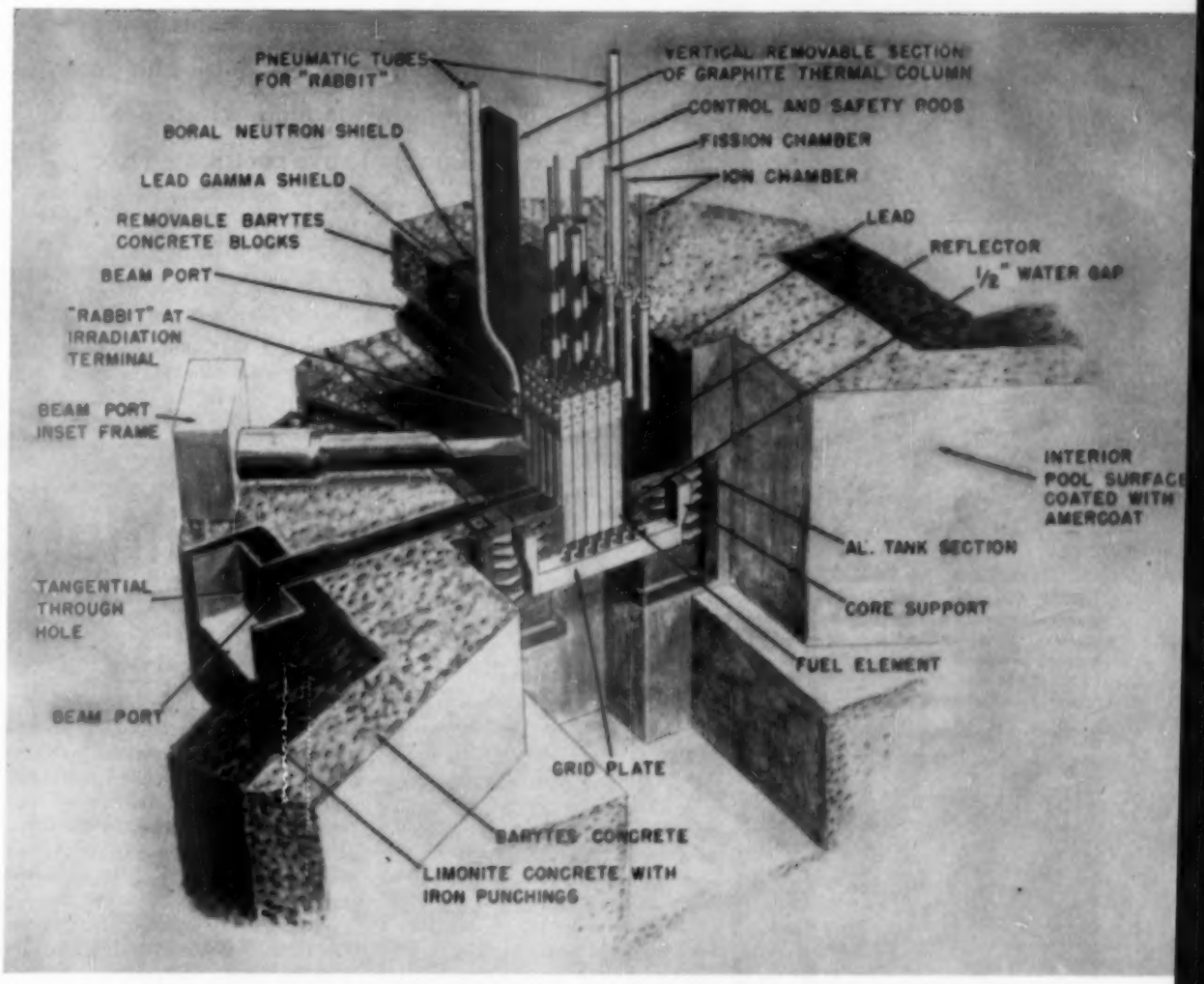
Coolant water goes through an evaporative cooler with a capacity of 1–2 Mw, but there is space for two more such coolers; the 3,400 gpm of demineralized water circulated in the system is sufficient flow for 5 Mw operation.



Omega West Reactor's shows principal features



OWR tank as seen from above. At bottom of tank is fuel grid plate at center with several dummy elements in position; thermal column is at top and experimental beam holes are on other three sides. Control rod system has been removed; ladder is, of course, temporary



Naval Research Laboratory research reactor has fixed graphite reflector surrounding movable core on three sides

nrl

The Naval Research Laboratory research reactor now under construction in Washington, D. C., is nearing completion, according to T. A. Bergstralh of NRL, and critical experiments are slated to begin in August.

This swimming pool will have a fixed graphite reflector surrounding the core, when the core, suspended from a rolling carriage, is at one end of the pool. Measurements on a critical assembly show the critical mass to be 2.7 kg in the three-side-graphite-reflected position; extrapolations give 3.4 kg for the cold clean critical mass in the pool position with water reflection on all sides. When the core is in the graphite-reflected position, seven regular and one straight-through beam ports are available for experimental purposes. Two vertical tubes to be used for pneumatic rabbits terminate tangentially to the core.

The thermal column has been deemphasized to make more beam ports available. The major portion of the column is now vertical.

Safety rods are oval aluminum tubes filled with a B-Pb mixture. Their value is ~3–4% $\Delta k/k$. The control rod is 347-type stainless steel with 0.2-in. wall thickness; its worth is ~0.6% $\Delta\ k/k$.

Provision is being made for two-bed ion-exchange demineralization of the pool water. Tests for water integrity of the pool are underway.

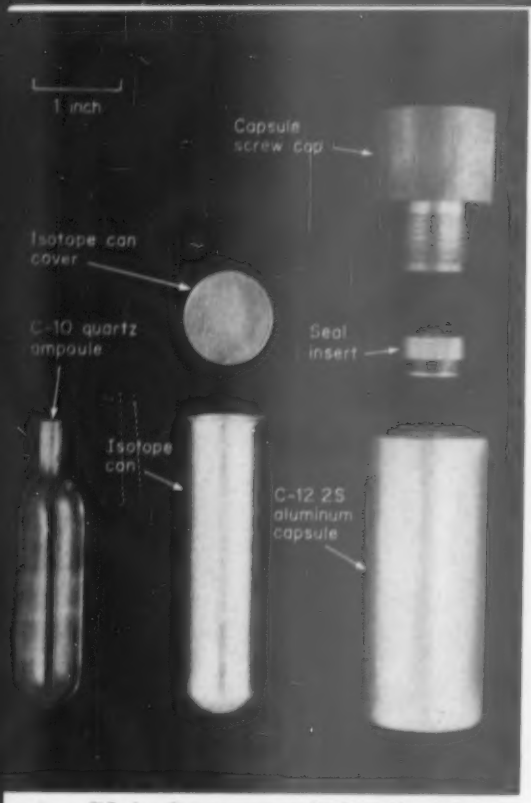


FIG. 1. Quartz ampoule (left) used in early experiments fits a standard ORNL isotope can (center). Vessel at right was designed to solve bursting problem. Screw plug seats against insert that has lead ring seal. Metal disk in insert is pressure relief and puncturing diaphragm

Experiments in neutron and gamma fields require remote extraction of liquids and gases as well as safety in handling. Here are several designs that have contributed to a simple, flexible system

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California Research Corporation, Richmond, California

Safe Containers

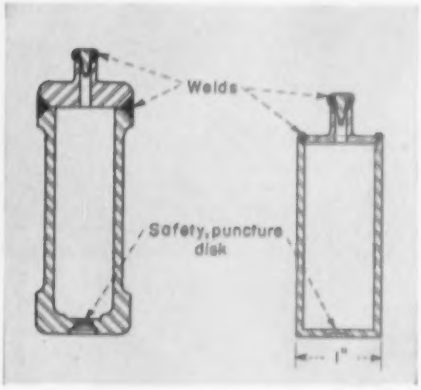

FIG. 2. Capsules of improved design have only welded closures. Tops are welded to bodies made from metal rod, and taper pins are arc welded into spouts after filling. Combination bursting and puncturing diaphragms are machined into bottom. Capsule at left is of magnesium; that at right is of stainless steel

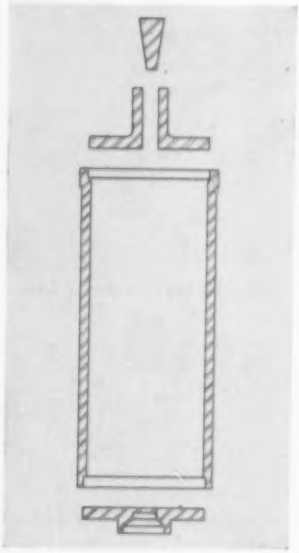

FIG. 3. Capsule fashioned from stainless-steel tubing costs only about 1/5 as much as steel capsule in Fig. 2. Top and bottom are made from bar stock and welded to body. Bursting disk is machined after bottom is welded to body lest welding process cause undesirable hardening of disk

IRRADIATION OF organic fluids in nuclear reactors poses peculiar problems of container design. Space limitations must receive major consideration, and vessels must be designed to withstand decomposition pressures of organic materials at a variety of test temperatures. Frequently one must recover evolved gas and measure its pressure. Consideration must be given to safe handling of the radioactive container after irradiation, and recovery of the irradiated fluid should be complete and without contamination.

Equipment has been developed for reactor exposures of organic materials at temperatures up to 850° F. Various capsules have been made and used. A preferred vessel, made from Type 410 stainless steel, embodies an all-welded closure and a combination safety and puncturing disk. Also developed were techniques for loading the containers and a special device for use with greases.

Equipment for handling capsules after irradiation was developed to provide for recovery of evolved gas and residue with a minimum of hazard. In this apparatus the capsule is punctured, gas pressure measured, and gas samples

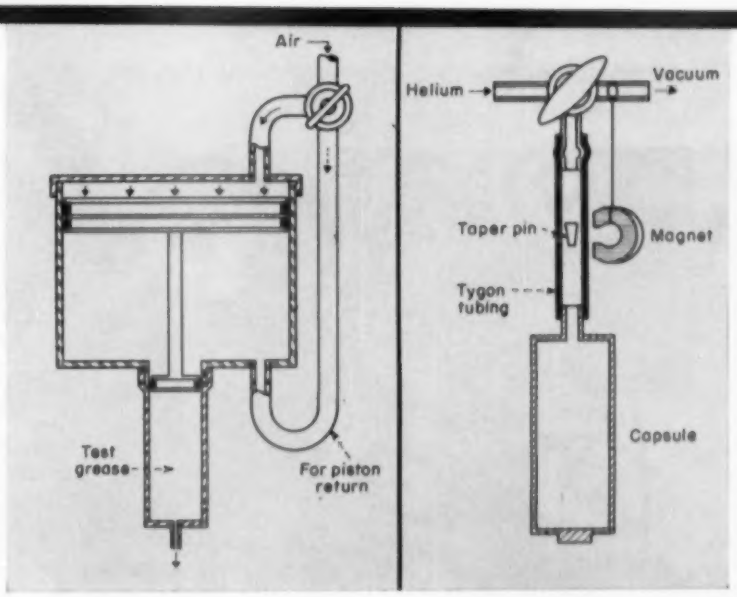

FIG. 4. Special filling device for greases. Large air cylinder acts on small piston (~1 in. diameter) that moves through cylinder holding about 12 gm of grease. Small piston is removable for cleaning and filling. Air pressure of 5 psi is sufficient for operation

FIG. 5. Small manifold attached with Tygon tubing to filled capsule permits substitution of helium blanket for air. Magnet controls position of taper pin until several alternations of helium and vacuum have completed substitution. Mallet blow seats pin for welding

Hold Organics for Irradiations

collected in one operation. A new capsule opener permits the removal of the vessel top without contaminating the contents with metal chips.

The result is a flexible, easily operated system for irradiation, handling, and recovery of organic fluids.

Capsule Design

In the early stages of the capsule-irradiation program, a quartz ampoule was used with an internal volume of about 10 ml (Fig. 1). The capsule is filled with liquid by means of an ordinary laboratory syringe. The neck is then sealed while the body is cooled in water. This capsule was used primarily in the Oak Ridge graphite reactor. When sealed, it is unsatisfactory because gas generated during irradiation either causes fracture or creates a hazard to personnel in handling because of variable and unknown bursting characteristics. It is satisfactory when used unsealed.

To solve this bursting problem and present less hazard, a vessel of about 12-ml capacity was made from 2S full-hard aluminum (Fig. 1). Table 1 gives the nominal composition of the 2S alloy, and Table 2 shows that the full-hard treatment provides good tensile strength up to 300° F. Problems of induced radioactivity are minimized by the use of this material.

Sealing is conducted in an airtight box with an inert gas atmosphere when desired. A hole through the center of the screw cap permits access to the diaphragm in the plug. This safety disk precludes rupture of the capsule, with possible undesirable disturbances within the reactor. Structurally, this vessel withstands about 4,000 psi, although the safety disk is set to burst at 2,500 psi.

Use of Aluminum Capsules

These 12-milliliter capsules have been used for exposures in 4 × 4-in. experimental holes of Oak Ridge and Brookhaven graphite reactors. The size is such that several (usually 16) can be exposed simultaneously in an aluminum oven fitted with heater ele-

TABLE 1—Nominal Composition of Capsule Metals

	Elemental composition (%)		
Element	*2S aluminum*	*58135 magnesium*	*410 stainless steel*
Aluminum	Balance	3	—
Magnesium	—	Balance	—
Copper	0.2	0.005	—
Iron	*	0.005	Balance
Manganese	0.05	0.005	1.0
Zinc	0.1	0.01	—
Beryllium	—	0.075	—
Carbon	—	—	0.15
Phosphorus	—	—	0.04
Sulfur	—	—	0.03
Silicon	*	—	1.0
Chromium	—	—	12.25

* Iron + silicon—1.0% maximum.

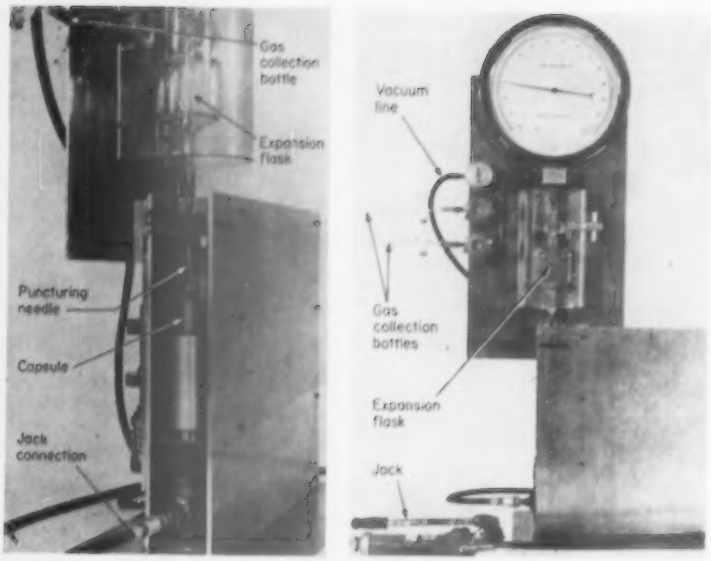

FIG. 6. Two views of apparatus built to collect and measure gas from decomposition of organics in capsules. Gas expands into known volume (~250 ml) of expansion flask, and original pressure is calculated from reading of 1-ft laboratory gage. Gage reads from −30 in. Hg to +60 psig with error <0.25 psi

ments to maintain selected temperatures. This vessel would be satisfactory for exposures up to about 400° F. By replacing the screw cap, the container can be reused after an appropriate decay period (about 4 wk).

Longer capsules have been exposed in various hydraulic and fuel channel facilities in the Oak Ridge and Hanford reactors.

The aluminum capsules are satisfactory for the experimental work for which they were designed. However, further work at higher temperatures revealed limitations that necessitated changes in design and material. As shown by Table 2, the hardness is drawn from 28 full-hard aluminum at temperatures above 300° F, and above 400° F its strength is reduced below tolerable limits. An improved design was developed to eliminate the lead seal ring that is less and less dependable at higher temperatures and to simplify the cumbersome procedure required for loading the vessel in an inert atmosphere.

Magnesium Vessels

To improve the strength of the vessel at intermediate temperatures, Type 58135 magnesium was substituted for the 28 aluminum. This alloy has a composition that provides low susceptibility to long-lived activation (Table 1). It was developed at ORNL.

TABLE 2—Tensile Strength of Capsule Metals

	Tensile strength (10^3 psi)			
	Aluminum		*Magnesium**	*Steel*
Temperature (° F)	*28*	*28 full hard*	*type 58135*	*410 SS*
75	13.0	24.0	41	89
212	10.5	21.5	34	83
300	8.5	17.5	22	79
400	6.0	6.0	13	76
500	3.5	3.5	8	74
600	2.5	2.5	6	73
700	1.5	1.5	—	71
800	—	—	—	66
900	—	—	—	55

* Courtesy of Dow Chemical Company.

The magnesium was fabricated not only into the design of Fig. 1, but also into the improved design shown at left in Fig. 2. This piece incorporated a filling spout with a $\frac{1}{16}$-in. hole.

This capsule has been used extensively in reactors and in gamma exposures at temperatures up to 500° F. A minor difficulty was occasionally experienced with corrosion by water. This generally is mitigated by removing all welding fluxes and thoroughly cleaning the exterior of the vessel. A further difficulty is the porosity of the Type 58135 magnesium supplied. This allows leakage of evolved gas and, occasionally, volatile liquids during irradiation.

Leakage did not occur through welds or bursting disks, indicating that both welding and work hardening closed the pores. This observation led to a burnishing operation on the entire capsule surface. In this step the capsule is placed in a lathe, and metal is smeared over the pores by means of a dull tool to obtain a permanent seal. With this provision, the vessel withstands pressures of about 6,000 psi at room temperature. Normally, the bursting disk is set for about 3,000 psi.

Stainless-Steel Capsules

For work at higher temperatures, Type 410 stainless steel is used (Table 2). Problems of induced radioactivity are much greater with this alloy. However, 410 stainless appears to be most attractive of all steel alloys considered from standpoints of strength and induced activity. The capsule shown at right in Fig. 2 is of this material. Internal volume is 22 ml, and the design follows closely that of the magnesium capsule.

Also in this capsule the bursting disk feature is retained, and the filling procedure remains essentially the same. This capsule withstands about 7,500 psi at room temperature without rupture; the bursting disk normally is adjusted to release at about 4,500 psi. Experience shows that such bursting characteristics prevail with a disk milled to a diameter of $\frac{3}{16}$ in. and thickness of 0.0040–0.0045 in. with the surfaces finished to an 8-μin. (root mean square) specification.

The stainless-steel capsules initially were fashioned from bar stock in the same manner as the magnesium capsules. Subsequently, a considerable cost saving was made by fabricating

the body from tubing stock (Fig. 3). The two are equivalent in strength.

The two steel capsules were used satisfactorily for irradiation at temperatures as high as 850° F. Normally, 10–12 ml of fluid was loaded into the vessel. In a few cases out of several hundred the pressure of the evolved gas was sufficient to rupture the bursting disk. No undue difficulties were observed in these instances. These capsules were used primarily in the Brookhaven reactor but are now preferred for all uses, including gamma exposures. The vessels become highly radioactive during neutron irradiations. However, with suitable precautions they have been handled readily after a three-day decay.

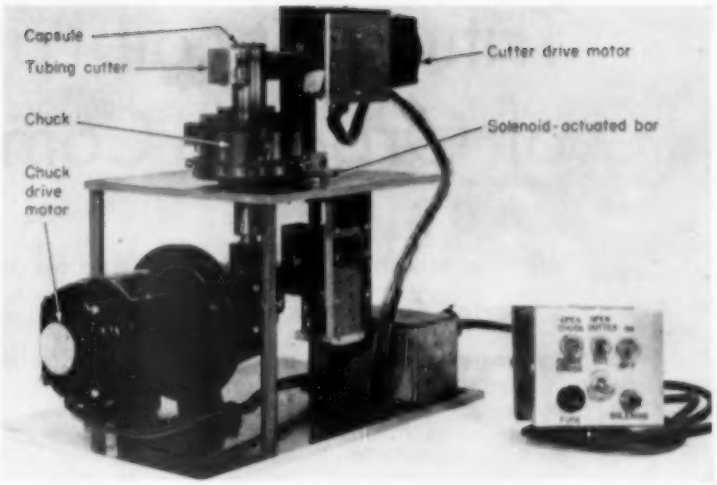

FIG. 8. Capsule opener consists of a motor-driven tubing cutter that bears against capsule gripped in standard lathe chuck. Rotation and closure of chuck and feed of cutter are actuated by remotely controlled motors. Solenoid-activated bar engages special lugs at base of chuck to stop rotation and permit opening and closing

Capsule Loading

Filling procedures vary somewhat with the nature of the material to be charged. Most liquids are handled easily by means of a suitable syringe. Solids that melt below 300° F are introduced with a preheated syringe or by pouring through a heated funnel. Higher melting solids are loaded by means of funnels and tampers. For materials such as lubricating greases the special filling device of Fig. 4 is used. The force of the piston is sufficient to introduce the grease through the small opening in the capsule lid.

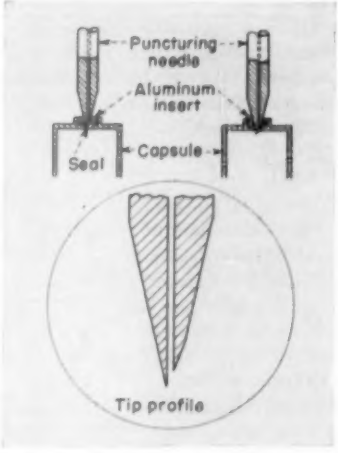

FIG. 7. Needle used to release gas through puncturing diaphragm has angled tip. This does not plug with metal during puncture as do straight tips. In puncturing, needle first seals against soft aluminum doughnut gasket that fits into safety-disk aperture. Remotely operated hydraulic cylinder of Fig. 6 forces capsule against hollow needle of hardened steel

After the capsule is filled, helium is substituted for the air in it as illustrated in Fig. 5.

The steel taper pin is placed in the tubing so that its position can be controlled with a magnet. Several applications of alternate vacuum and helium remove air and leave a blanket of helium over the sample. In the final step the taper pin is seated with a mallet and then welded.

Capsule Penetration

Penetration equipment is shown in Fig. 6. The over-all expansion factor can be controlled as desired; a factor of 60 has been satisfactory for most cases.

In puncturing (Fig. 7), the evolved gas is released into the previously evacuated apparatus. By means of valving shown in Fig. 6 the gas pressure is measured on the gage, and samples are collected to complete this phase of the recovery.

A 4-inch lead shield generally is placed between equipment and operator. Capsules indicating 5–7 r/hr on contact have been handled routinely; capsules as active as 45 r/hr have been handled using special precautions without exceeding radiation limits for personnel. One difficulty with the equipment involves handling of liquids reduced by irradiation to near-plastic solids. Such materials tend to plug the penetrating needle or to "foam" into the gas expansion flask. Occasionally, a pressure reading is lost for this reason. Except for such minor difficulties, this apparatus has been very satisfactory.

Capsule Opener

After the measurement and the collection of the gas, it is necessary to retrieve the fluid sample itself. The punctured container, with appropriate handling dictated by its radioactivity, is taken from the puncturing apparatus and placed in the capsule opener (Fig. 8). A gear-type reversible motor with an output speed of 9.6 rpm drives the chuck. The cutter drive motor is reversible and rotates the cutter blade at about 0.02 in./min. Chuck speed and cutter travel have been selected to handle any of the metallic capsules described previously. About 2.5 min is required to sever the lid from the stainless capsule. Travel of the cutter wheel is controlled by two limit switches so that the operator need not be in attendance during the operation. A major advantage is the complete absence of metal chips or filings from the cutting operation. This simplifies recovery of the organic sample and reduces the radiation hazard.

* * *

The authors express their appreciation to V. C. Davis, M. A. Ausman, and C. L. Blanton of the Richmond Laboratory of California Research Corporation for assistance in design and fabrication of the equipment.

Tritium-Recoil Labeling of Organic Compounds

When a mixture of a lithium salt and an organic is irradiated in a reactor, fast tritons break chemical bonds and exchange with hydrogen. Here is a review of this labeling method

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LABELING OF ORGANIC COMPOUNDS can be accomplished by employing nuclear reactions that produce C^{14} or tritium atoms with large kinetic energies (*1–3*). Such atoms can break bonds and enter chemical combinations to form tagged compounds. A summary of the present status of recoil labeling with tritium is presented here. Basic studies of the mechanisms and kinetics of such reactions have been reviewed elsewhere (*4, 5*).

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Experiments have been performed to determine conditions that produce high specific activities when a mixture of a lithium salt and the compound to be labeled is irradiated in a reactor. The useful specific activity depends on the per cent entry of the tritons into the organic molecule, the radiation damage that takes place during the irradiation, and the quality of the chemical process that separates the labeled compound from the byproducts.

Recoil Labeling

The kinetic energy of a fast ion or atom produced in a nuclear reaction causes it to recoil and move through the surrounding medium until through ionization and collision, its energy is reduced to the range of chemical-bond energies. The kinetic energy retained at the end of the recoil track is largely expended in breaking one or more chemical bonds.

Combination of the recoil atom with one of the fragments produced makes a new radioactive molecule. This molecule may be identical to those with which the fast atom reacted except for the substitution of a radioactive isotope. In the case of tritium, 6–50% of the activity substitutes for ordinary hydrogen and produces no other permanent change in the organic molecule. This fraction is known as the "per cent entry."

$Li^6(n,\alpha)T$

Tritium is produced in high yield by the slow-neutron reaction $Li^6(n,\alpha)T$. This reaction has a cross section of 945 barns in an isotope with 7.5% natural abundance. The 2.7-Mev tritons produced have a range of about 50 μ in condensed media. In contrast with other recoil nuclides, this long range makes it unnecessary for both the source of the fast atom and the material with which it reacts to be in a homogeneous irradiation system. It is sufficient to prepare a powdered mixture, slurry, or gel of a lithium salt and the compound to be labeled and expose it to slow neutrons.

Tritons produced recoil through the mixture and come to rest in accordance with the stopping powers of the com-

Standard Labeling Techniques

There are several standard techniques by which isotopically labeled compounds can be prepared:

1. Chemical synthesis. *Chemical synthesis of the desired compound from simpler molecules, at least one of which is radioactive, is applicable to all chemicals that can be synthesized and can yield high specific activities. It is especially suitable for specifically labeled materials (but for given tracer applications this may not be desirable). It frequently involves a long procedure and low over-all yield.*

2. Chemical exchange. *The compound into which the radioactivity is to be introduced is mixed with active material under catalytic conditions that promote rapid exchange of the activity. This method often is inapplicable since no exchange will take place or the molecule is not stable under required catalytic conditions. Sometimes activity is introduced only into the more labile positions.*

3. Biosynthesis. *The desired molecule is isolated from a plant or animal raised on radioactive nutrients, such as $C^{14}O_2$, HTO, etc. This method is widely applicable. But yields and specific activities may be limited.*

Compounds Labeled by Tritium Recoil

Compound	*Molecular weight*	*Lithium source*	*Weight Li salt (%)*	*Entry (%)*	*Survival (%)*	*Flux (10^{13} n/cm²/sec)*	*Nonlabile specific activity (dpm/mg)*	*Exposure time*	*Experimenters*
Methane	16	several	>90	47	~100	5	10^4	30 s	Wolfgang, Eigner, Rowland
Ethane	30	LiCl	>90	41	~100	5	10^4	30 s	"
Ethyl alcohol	46	LiCl	12	23	≥95	2	8×10^4	6 h	Hoff, Rowland
Benzoic acid	122	Li_2SO_4	3	25	n.m.*	1	2×10^5	3 d	Kaplan
		Li_2CO_3	17		35	2	2×10^6	40 h	Markowitz, Rowland, Wolfgang
		"	5		66	2	"	154 h	
		"	1		56	2	"	700 h	
Nicotinic acid	123	Li_2SO_4	3	23	n.m.	1	2×10^5	3 d	Kaplan
			10	6	~50%	2	3×10^5	2 d	Christman, Anderson
o-Toluic acid	136	Li_2SO_4	3	25	n.m.	1	2×10^5	3 d	Kaplan
Phenylacetic acid	136	Li_2CO_3	3	31	>95	2	2×10^4	3 h	Wolfgang, El-Atrash
Salicylic acid	138	Li_2SO_4	3	31	n.m.	1	2×10^5	3 d	Kaplan
trans-Cinnamic acid	148	Li_2SO_4	3	26	n.m.	1	2×10^5	3 d	Kaplan
Isopropyl benzoate	164	Lithium myristate	14	17	n.m.	1	4×10^5	5 d	Garnett, Brown
o-Phthalic acid	166	Li_2SO_4	3	24	n.m.	1	2×10^5	3 d	Kaplan
Anthracene	178	Li_2SO_4	3	37	n.m.	1	3×10^5	3 d	Kaplan
Glucose	180	Li_2CO_3	50	10	>95	.006	6×10^3	3 d	Rowland, Turton, Wolfgang
Galactose	180	Li_2CO_3	10	12	≥32	2	2×10^5	27 h	"
α-Methyl glucoside	194	Li_2CO_3	10			2	$\sim 2 \times 10^5$	1 d	Rowland, Turton
2-Me-2-n-Pr. 1,3-Propanediol Dicarbamate	218	Li_2CO_3	3	6	25–50	2	1×10^5	3 d	Rowland
Diacetone glucose	259	Li_2CO_3	10			2	$\sim 2 \times 10^5$	1 d	Rowland, Turton
Glucose diethyl mercaptal	286	Li_2CO_3	10			2	$\sim 2 \times 10^5$	1 d	Rowland, Turton
Cholestane	344	Li_2CO_3	10	19	≥17	2	4×10^5	29 h	Tsutsui *et al.*
Methyl Cholate	423	Li_2CO_3	10	17	≥10	2	3×10^5	24 h	Tsutsui *et al.*
Reserpine	608	Li_2CO_3	10	18	≥ 6	2	2×10^4	2 h	Rowland, Numerof
		Li_2CO_3	3	18	≥10	2	2×10^5	3 d	"

* n.m. = not measured, but at least 25%.

ponents. After irradiation the labeled compound is purified from the other products also formed (*3*). Scope of this method is indicated by the table.

Specific Activity

If a compound is intimately mixed with up to ½ its weight of Li_2CO_3, the specific activity induced by irradiation is 10^3 *EPFT* dpm/mg, where *E* is per cent entry of tritium into labeled but otherwise unchanged parent compound (generally 10–30%—see table), *P* is Li_2CO_3 in mixture (%), *F* is neutron flux (units of 10^{13} n/cm²/sec), *T* is irradiation time in days. *E* is a constant for the compound irradiated. The numerical coefficient will be different for other lithium salts.

From this expression it is seen that with neutron fluxes normally available specific activities of 10^5–10^6 dpm/mg can be obtained by irradiations of about one day's duration.

However, the maximum specific activity that can be induced by the tritium-recoil method is determined not only by incorporation of tritium into the parent, but also by the rate at which organic molecules, labeled and unlabeled alike, are destroyed by the radiation of the reactor. Since recoil tritium must dissipate 2.7 Mev before it can be incorporated; it is apparent that a large amount of damage is done along its path. Furthermore, the alpha particle, recoiling with 2.1 Mev from the Li^6, will do damage along its path, and the general background of fast neutrons and gamma radiation will contribute additional destruction.

Survival Conditions

Gross radiation destruction during a given irradiation is reflected in the per cent survival in the table. Under fixed irradiation conditions, specific activity can be increased by longer irradiation only at the expense of radiation destruction of some material. As survival decreases, larger percentages of radiation-damaged materials, also labeled, will be present.

The useful limit to specific activity for a given compound will depend on the availability of a procedure for isolating a chemically and radioactively pure sample of the parent from large amounts of damaged material perhaps chemically similar.

Survival varies widely with conditions and the nature of the compounds irradiated. Probably the most important fact illustrated in the table is that the fraction that survives under similar conditions, and consequently obtainable specific activities, usually decrease with increasing molecular weight.

Destruction Rate

The rate of destruction will depend upon the susceptibility of the com-

Should You Use Tritium Recoil? . . .

The user must decide whether the tritium-recoil method is preferable to older techniques. It will help to consider the advantages and limitations of the tritium method:

- *Scope is probably universal.*
- *Large quantities of active material are prepared readily.*
- *The method is relatively easy to use. Most of the work is associated with purification after synthesis.*
- *Low irradiation costs and simplicity make the method inexpensive.*
- *Moderate specific activities (10^5–10^6 dpm/mg) are obtainable in compounds of molecular weights up to about 600. Only low specific activities may be obtainable with high-molecular-weight compounds.*
- *Nonuniform, nonspecific labeling relative to position in the molecule is usual.*
- *In tagged organic compounds the isotope effect from substituting H^3 for H^1 may be a disadvantage compared with C^{14} labeling. In tracer studies this will be important only if a reaction involving the C—T or C—H bond occurs. Hydrogen is inherently more labile than the skeletal carbons, and some of the tritium may be lost by exchange under extreme conditions. However, the tritium in the obviously labile positions such as OH groups is removed before use of the tracer.*
- *Tritium must be counted through its soft (19 kev) β^- particle. But at present, there are convenient methods available that make tritium counting hardly more difficult than the assay of C^{14} (12).*

pound to damage from a variety of radiations and the relative intensities of each. Benzoic acid experiments under optimum conditions in the Brookhaven reactor indicate that most of the radiation damage is done by recoiling alphas and tritons (6). If it is assumed that all of the damage is done by these energetic particles, a G value (molecules destroyed per 100 ev) can be calculated in reasonable agreement with the G values obtained for benzoic acid with Co^{60} γ-radiation.* An order-of-magnitude estimate of radiation damage to be expected in an untried compound can be obtained by calculating survival on the basis of G values known from other experiments, preferably heavy-ion bombardments. Such a calculation becomes more liable to error as the amount of degraded material rises, and extrapolation to 5–10% survival is very uncertain.

Experimental Techniques

We have sought to determine the best procedures for tritium-recoil labeling. The usual way is to mix lithium salt with the powdered compound to be activated, wrap the mixture in aluminum foil, and irradiate it in a reactor. Kilogram and larger samples can be irradiated; size limit is determined by facility capacity, the necessity for adequate heat dissipation, and self-shadowing of Li^6.

The container should be vented to allow gases to escape, and elements such as Na, Cl, and P that become inconveniently radioactive should be avoided if possible.

After irradiation the activated compound is separated from gross degradation products—often by solution and crystallization. After further purification (e.g., by chromatography) the radiochemical purity of the sample should be checked by ascertaining whether its specific activity remains constant through steps that tend to fractionate impurities. Fractional recrystallization of the compound or a derivative from one or more solvents is most commonly used.

Some tritium replaces labile hydrogen atoms such as those in hydroxyl groups. In most procedures this activity will be rapidly "washed out" and removed.

Optimal Conditions

Various irradiation conditions have been tested to determine the optimal conditions for producing high specific activity and high survival simultaneously. Probably the most significant observation is that the concentration of lithium salt in the mixture is important. Although it might seem desirable to increase the lithium concentration to reduce the time required for a given specific activity, it has been shown experimentally that survival for a given specific activity in benzoic acid shows a maximum in the range of 3–10% lithium salt for 2×10^{12} n/cm²/sec (6).

Time required with lower percentages of lithium salt is sufficiently long that damage from the general radiation background becomes important. Explanation of the drop in survival above 10% is less certain, but it may be related to the heat produced. The energy production per gram of mixture is 0.25 calories/min/gm for each per cent of Li_2CO_3 in a flux of 2×10^{12} n/cm²/sec. Dissipation of this energy can be a major problem in materials with low thermal conductivity.

Particle size. Since the recoil range of 2.7-Mev tritons is much longer than the average particle diameter of finely ground powders, larger particle sizes can be used to keep as much of the path of the recoil atom as possible in the original salt particle. This avoids radiation damage to organic material along the initial portion of the path. The recoil range of the 2.1-Mev alpha particles from the reaction is only about 20% of that of the tritium atoms.

Thus it is possible to choose particle sizes such that a large fraction of the alpha particles never emerge from the original macroscopic particle of lithium salt in which they are produced while all of the tritons escape with reduced energies. Experiments with particle sizes have confirmed that survival rises with larger particles in the preparation of the same specific activity in the same compound (6, 7). It should be noted that if the particle size is greater than the recoil path of the triton, Eq. 1 will no longer hold.

Other Li salts. Irradiations have been performed with several different lithium salts. The choice has no effect on the nuclear reaction and can be made for convenience in chemical processes. For example, $Li_2SO_4 \cdot H_2O$ naturally forms large particles; LiCl is readily soluble in many or-

* From the table there is 66% survival of benzoic acid for a mixture of 1.0 gm organic and 0.050 gm Li_2CO_3 after 154 hr in a flux of 2×10^{12} n/cm²/sec.

G = molecules destroyed/100 ev absorbed $= 1.7 \times 10^{21} \times 10^2/2.6 \times 10^{23} \cong 0.6$

G of Co^{60} γ-radiation $\cong$ 0.4–0.5 (R. Noller, B. Tolbert, UCRL-2841, 1955)

ganic liquids, making preparation of a slurry unnecessary; Li_2CO_3 is not hygroscopic and produces no significant radioactivities except tritium.

Radiation. Composition of radiation is quite important. A high-intensity pure thermal-neutron flux is ideal since other radiations contribute to destruction without adding to tritium production. Damage is caused by energetic protons from the knock-on reactions of fast neutrons and by the interactions of gamma radiation. In the Brookhaven reactor there are some irradiation facilities with neutron fluxes of 2×10^{12} n/cm²/sec and few fast neutrons. These are the optimal facilities available with this reactor for they have an ambient temperature of 45° C or less, allowing exposure of a wide variety of organic compounds without thermal decomposition or reaction.

Atmosphere. Samples irradiated in a helium atmosphere showed about the same extent of radiation damage as in air, although the character of the irradiated material appears to change (*8*). Irradiation at −196° C does not appear to change the amount of damage decisively. Another variable, now under investigation, is phase change. Other factors still may be influential or dominant in individual cases.

Position of the Label

Usefulness of a labeled compound may depend on the location of the activity in the molecule. Compounds synthesized by nonrecoil methods usually fall into two groups: uniformly labeled, with specific activity the same for each position in the molecule, or specifically labeled, with all radioactivity contained in one particular position or grouping. Chemical synthesis often can be used to produce specifically labeled compounds, while biosynthesis and chemical exchange usually produce uniformly labeled compounds.

Specific labeling is especially convenient for subsequent analysis but is often limited to certain positions in the molecule because of synthesis problems. Some reactions used in synthesis and especially in exchange are not simple. They produce labeled compounds neither specific nor uniform that have varying specific activities in most or all of the available positions.

C^{14}-Recoil Labeling

C^{14}-recoil labeling using the $N^{14}(n,p)C^{14}$ reaction is also applicable, especially in those cases for which tritium is an unsatisfactory label. However, the specific activities obtainable with C^{14} recoil are at least two orders of magnitude less than those for T recoil because of the much longer half-life and substantially lower values for per cent entry.

Moreover the short recoil range of C^{14} necessitates preparation of homogeneous irradiation systems, which is sometimes tedious or impossible.

Position of Recoil T's

Generally, tritium-recoil-labeled materials contain activity in all or nearly all hydrogen positions, but with different specific activities. Variation within a particular molecule can be extreme. For example, the seven nonlabile hydrogens in glucose contain 0–29% each of the total nonlabile activity (*9*).

Differences also have been demonstrated in specific activity of different benzoic acid positions, meta containing 20% less than the average of ortho and para. Ring hydrogens of *o*-toluic acid contain 2.3 times as much activity as the methyl hydrogens. Specific activities of primary, secondary, and ring hydrogens in isopropyl benzoate are in the ratios 1.0:1.4:2.7 (*7, 10*). Distribution of tritium activity in glucose isolated from irradiated glucose derivatives is different from that obtained for irradiated glucose itself (*11*).

This nonspecific and nonuniform distribution of activity within recoil-tritium-tagged compounds is not important if the entire molecule is followed unchanged. However, if the tracer application involves breakup of the molecule, a knowledge of activity distribution in the molecule may be necessary.

Tagged Byproducts

As only 10–30% of the tritons usually show up in the parent molecule, a larger number of tritium atoms must appear in other molecular species. Usually no carrier is present for these; consequently, they are produced in high specific activities. In some systems much of the activity appears in simple gases such as hydrogen, methane, ammonia, etc. But 10–50% may be present in more complicated substances that could be valuable tracers if separated from the parent molecule.

Specific activities of these compounds are limited only by ability to separate trace amounts from irradiated targets. The total activity in a given compound usually will be small compared to that in the tagged parent compound since the tritium generally will be divided among a large number of degradation, isomerization, and polymeric products.

Specific Labeling

Tentative mechanisms for the reactions of recoil tritons in organic systems indicate strong possibilities for isolating degradation or isomeric products that have all or most of their radioactivity in a single position in the molecule (*9*). Such products could be postulated in the following situations:

1. Entry of the tritium atom into the molecule is accompanied by inversion at an asymmetric carbon atom. This yields an isomer of the parent molecule labeled only at the inverted carbon atom.

2. Rupture of a C—C bond is followed by combination of the tritium atom and one of the resulting radicals at the broken bond.

These types of systems are now being investigated.

* * *

The authors wish to acknowledge the kind cooperation of W. G. Brown, L. Kaplan, and D. Christman for permission to quote their results, mostly prior to publication, and for informative discussions of the experiments. We also wish to acknowledge several valuable discussions with R. C. Anderson and A. P. Wolf of the Brookhaven National Laboratory.

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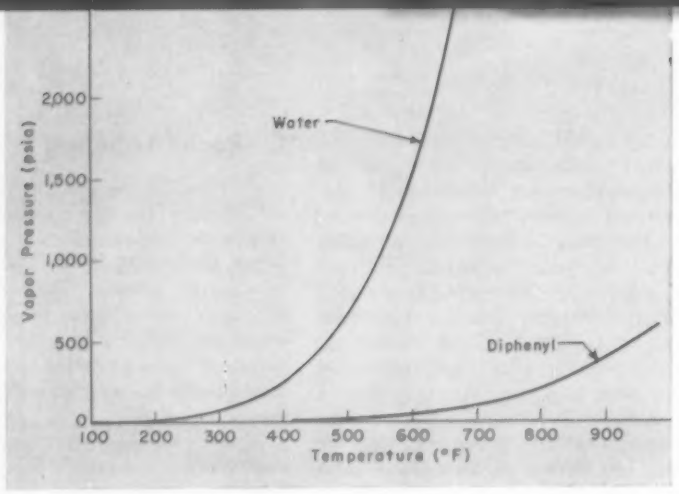

FIG. 1. Comparison of vapor pressures of water (8) and diphenyl (3). With diphenyl as coolant and with primary coolant system at 600° F and 300 psi, power density of 100 kw/l of core volume can be attained

The Case for

Organic Coolant-Moderators for Power Reactors

Compared to water:

PRO—low pressure, no activation, reduced corrosion, better lubrication

CON—radiolytic breakdown, low power density, high melting point

By G. A. FREUND
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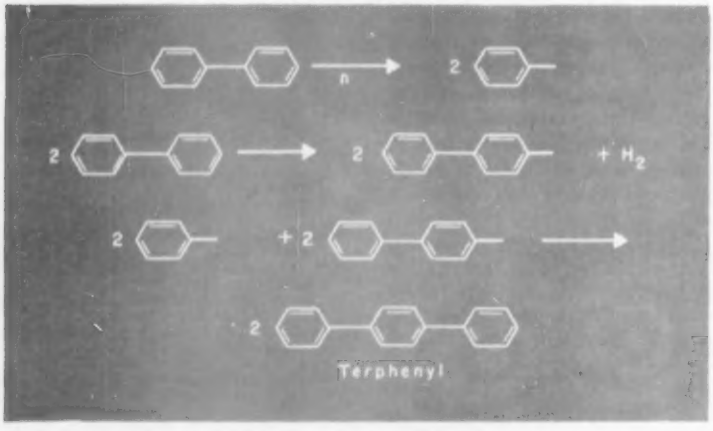

FIG. 2. Mechanism of radiolytic breakdown of diphenyl

An organic-moderated reactor experiment (OMRE) is being built at the National Reactor Testing Station for AEC primarily to test the heat and radiation stability of the organic materials (*1*). Organic breakdown and replacement would add to reactor operating cost. Also, the comparatively low power density obtainable with organic coolants would require higher fuel inventory. However, the advantages of low pressure, no activation, and low corrosion lend themselves ideally to a plant that is economical to construct and to maintain. On the basis of these considerations, this article attempts to evaluate organics as coolant-moderators for power reactors.

To begin with, it is desirable to put this discussion in the proper perspective. Organic reactors are not a step in the direction of such reactor ultimates as ease of fuel processing (promised by the homogeneous reactor), fuel economy and high power density (promised by the fast breeder), or high cycle efficiency (promised by the gas-turbine reactor). The advantages they do offer are given in detail below.

The most radiation-stable organic structure, as evidenced by capsule-type irradiation tests, is the benzene ring (*2*). Joining two benzene rings results in diphenyl ($C_{12}H_{10}$), which is currently of primary interest. Comparison with an established coolant-moderator, such as high-pressure light water, provides an effective evaluation of diphenyl.

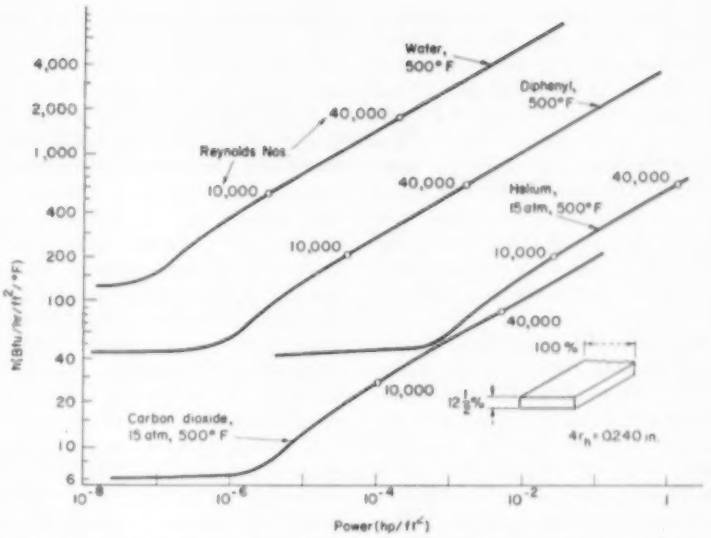

FIG. 3. Heat-transfer coefficient (h) vs. friction power for various coolants. For given pumping power, water has 5× heat-transfer coefficient of diphenyl. However, it must be considered in comparing power density that diphenyl permits higher metal-surface temperatures (e.g., 800° F vs. 650° F)

Advantages of Diphenyl

Diphenyl has four primary advantages as a coolant-moderator for reactors:

Low vapor pressure. Diphenyl boils at 492° F, and even above the critical temperature of water its pressures are low [200 psi at 785° F and 300 psi at 850° F (*3*)]. For a comparison with water, see Fig. 1.

No activation. Since diphenyl contains no oxygen, only carbon and hydrogen, there is almost no activation at all in the coolant itself. Therefore secondary shielding would be required only to protect against impurities in the diphenyl.

Reduced corrosion. The very much reduced corrosion attack by diphenyl compared to water permits the use of more conventional materials and puts less emphasis on foolproof methods of cladding fuel elements. In over 4,000 hr of static testing in 500° F and 680° F diphenyl, uranium and high-uranium alloys have shown little tendency toward the catastrophic failure characteristic of exposure in high-temperature water. Corrosion rates are considerably less than those of the best comparable materials in water. In the same tests, structural materials exhibit generally no more attack than stainless steel in water at the same temperature; these include 28 aluminum and aluminum alloys, nickel, carbon steel, stainless steel, and zirconium.

Better lubrication. Wear tests of stainless steel and carbon steel in diphenyl and water have shown the following for diphenyl: (a) lower torque requirements for a given applied load, (b) less surface wear, and (c) less tendency toward galling. Diphenyl has been mentioned as a lubricant additive to improve film strength (*4*).

Disadvantages of Diphenyl

There are primarily three disadvantages to diphenyl; these serve to set some operating limits on diphenyl-cooled reactors:

Radiation and thermal breakdown. Radiolytic (irradiation) breakdown has been determined as 30% per 10^{18} cm^{-3} fast-neutron exposure both in static (*2*) and dynamic tests (*5*). This means 30% of the original diphenyl has been changed, primarily by polymerization, into longer-chain terphenyl compounds (three benzene rings) with the resulting release of hydrogen (*5*). This process is shown in Fig. 2. Actually the hydrogen released seems to go toward saturating the products of an occasional benzene-ring cleavage. As a result, the gaseous decomposition products are primarily hydrocarbons.

Pyrolytic (thermal) breakdown follows a similar pattern, resulting in very much the same decomposition products (*6*); 800° F is apparently the maximum permissible metal surface temperature in contact with coolant. At 800° F there is some breakdown, but no deposition on out-of-pile heat-transfer surfaces (*6*). Above 800° F there seems to be an acceleration of irradiation breakdown (*2*). Finally, with coolant at 750° F there is no change in vapor pressure in a 100-hr test, while at 800° F there is a gradual increase from 225 psi leveling off at 270 psi (*5*). Detailed studies of fouling on in-pile heat-transfer surfaces are being reserved for the reactor experiment.

Heat transfer. The heat-transfer coefficient is given by

$$h \propto k^{0.5}\, c_p^{0.5}\, \mu^{-0.4}$$

where h = heat-transfer coefficient, k = thermal conductivity, c_p = specific heat, and μ = viscosity. At 500° F, the values in English units are

	k	c_p	μ
Diphenyl	0.076	0.62	0.65
Water	0.36	1.15	0.26

Substituting these values in the proportionality

$$\left(\frac{1}{4.7}\right)^{0.5}\left(\frac{1}{1.8}\right)^{0.5}\left(\frac{2.5}{1}\right)^{-0.4} = 0.22$$

or the heat-transfer coefficient for diphenyl at 500° F is about 22% of that for water. It can be seen that the primary effect is due to the low thermal conductivity typical of organics.

A more practical comparison for the reactor designer is shown in Fig. 3, which is a plot of heat-transfer coefficient vs. flow friction power (pumping power) per square foot of heat-transfer surface for a given rectangular channel

(7). Selecting a given pumping power, say 10^{-2} hp/ft², one finds the heat-transfer coefficient of carbon dioxide to be 100 Btu/hr/ft²/°F at 500° F and 15 atm, 150 for helium, 1,000 for diphenyl, and 5,200 for water. Thus water has over five times the heat-transfer coefficient for a given pumping power. Basic heat-transfer data show that the factor of five holds for turbulent flow in any tube-flow geometry, i.e., inside round tubes or in rectangular channels.

However, the foregoing is not an absolute comparison of reactor power density since with diphenyl higher metal-surface temperatures are permissible (say 800° F vs. 650° F). As a result, the heat transfer "product" of coefficient multiplied by film temperature drop is at least one-half that of water.

It is evident that radiation exposure leading to polymerization and higher viscosity would result in further reduction of heat-transfer coefficients.

High melting point. Diphenyl melts at 156° F, requiring external heating to keep it molten during reactor shutdown. Other similar materials have lower melting points—a eutectic mixture of diphenyl with terphenyls melts at 70° F, and there are commercial products such as partially saturated diphenyl and isopropyl diphenyl that have pour points below 32° F. Compared to diphenyl, these low-melting products have (a) lower vapor pressures, (b) poorer heat-transfer properties [coefficients are about two-thirds at the same velocity (*5*)], and (c) about equal or poorer radiation and thermal stability (*5*).

Physical Constants

Hydrogen is the primary contributor to the physical constants of both diphenyl and water.

The lower hydrogen density of diphenyl (0.31×10^{23} vs. 0.46×10^{23} atoms/cm³) results in poorer slowing-down properties. The Fermi age (τ) is higher (91 vs. 65 cm²) and the slowing-down power ($\xi\Sigma_s$) is less (0.64 vs. 0.93 cm^{-1}). Lower hydrogen density also means less absorption. As a result, the moderating ratios are the same (about 100). All values discussed are at 600° F.

Effect on Plant Design

The lower heat-transfer rates and the poorer slowing-down properties of diphenyl require somewhat larger cores than for pressurized-water reactors—both for heat removal and for comparable neutron leakage.

With a maximum hot-spot temperature of 800° F and a coolant temperature of about 600° F, satisfactory power densities of the order of 100 kw/l of core volume can be attained without excessive pumping requirements. Such a system would yield 600-psi steam, but would almost surely require zirconium as the low-cross-section fuel cladding. It would operate at 300-psi primary system pressure (vs. 2,000–2,500 psi for the normal temperature range of water-cooled power reactors).

If fouling of heat-transfer surfaces turns out to be no problem, one might be willing to tolerate some thermal breakdown and raise the maximum permissible hot-spot temperature. This would require a higher operating pressure (possibly up to 500 psi) but would result in increased power density and/or steam pressure. Other alternatives include the use of aluminum-alloy cladding at a reduced hot-spot temperature with resulting sacrifice in power density and steam pressure. Also, since a cladding failure will have far less serious consequences than in a water reactor, simple and inexpensive cladding methods should be possible resulting in extremely thin clads. Then an inexpensive high-temperature cladding material with a cross section higher than zirconium can be considered.

The reduced pressure of a diphenyl system means a reactor pressure vessel 1 to 1½ in. thick instead of 6–8 in. for water. Such a thinner vessel with no inner stainless cladding would represent a major saving in itself. Carbon steel could be used throughout the primary system. Because of better lubrication, unusual materials would not be needed for gears, bearings, and other wear surfaces.

To afford protection against fission-product release after a cladding failure, some secondary shielding probably will be desirable. However, during normal operation, limited access to all equipment except the reactor should be possible, simplifying operating and maintenance problems.

Purification of irradiated diphenyl can be done continuously by distillation. The decomposition products, together with nonorganic impurities, are left behind in the bottoms. Thus the still is comparable to the ion-exchange system of a water reactor. However, at 15¢/lb, the cost of diphenyl makeup will make a measurable contribution to the price of electricity.

* * *

In addition to cited references, the material in this article is based on work done at Argonne under auspices of U. S. Atomic Energy Commission by E. F. Fricke, L. W. Fromm, H. P. Iskenderian, P. W. Kleimola, and G. C. Milak.

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Terphenyl vs. Diphenyl

Since, in the radiation damage of diphenyl, terphenyls are the primary product, it would appear that one should start with diphenyl as the reactor coolant instead of giving the radiation damage a head start toward making unusable long-chain tars. The reduction in operating pressure from 300 to 100 psi does not seem to be a significant advantage, especially since terphenyls are considerably more expensive.*

One compromise might be a low-melting diphenyl-terphenyl eutectic as starting material with diphenyl as make-up. This would probably complicate purification and make-up and might not result in an operating mixture with a low enough melting point.

It looks as though some compound like isopropyl diphenyl with a pour point of about −40° C is potentially more of a competitor to diphenyl than the terphenyls.

* Editor's note: *cf.* E. Colichman, R. Gercke. Radiation stability of polyphenyls, Nucleonics **14**, No. 7, 50 (1956).

NUCLEONICS DATA SHEET No. 15

Induced Radioactivity

Nomogram for Radioactivity Induced in Irradiation

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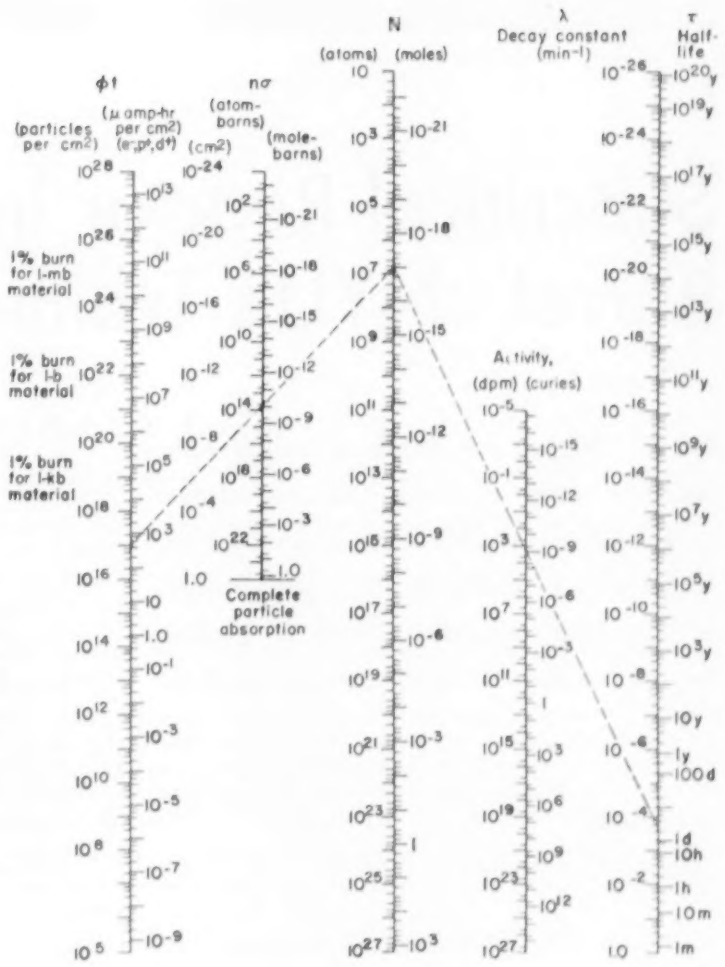
FREQUENT CALCULATIONS in radioactivity laboratories answer such questions as this: If a sample is irradiated in a flux for a specified time, how many atoms are transmuted? How much radioactivity is induced?

The known quantities of one problem may be the unknowns of another: If a certain irradiation produces a measured activity, how much of a particular nuclide was originally present? In terms of an observed activity and half-life, what is the capture cross section?

This nomogram can be used for determinations of this type. It summarizes the relationships among:

1. Total exposure ($\phi \times t$)
2. Product of amount of material in sample (n) and activation cross section per atom (σ)
3. Amount of material transmuted (N)
4. Amount of resulting activity
5. Decay constant (λ) or half-life (τ).

Example: Activation analysis of a sample of U^{238} exposed to 10^{17} thermal neutrons/cm² produced 1,500 dpm of 2.34-day Np^{239}. The nomogram shows that there are 7×10^{6} atoms of Np^{239} in the sample. A second line from ϕt to N shows that the target material had a total cross section of 10^{-18} mole-barns. Since the thermal-neutron capture cross section of U^{238} is 2.8 barns, there were 3.6×10^{-11} moles of U^{238}, or 8.5×10^{-9} gm.



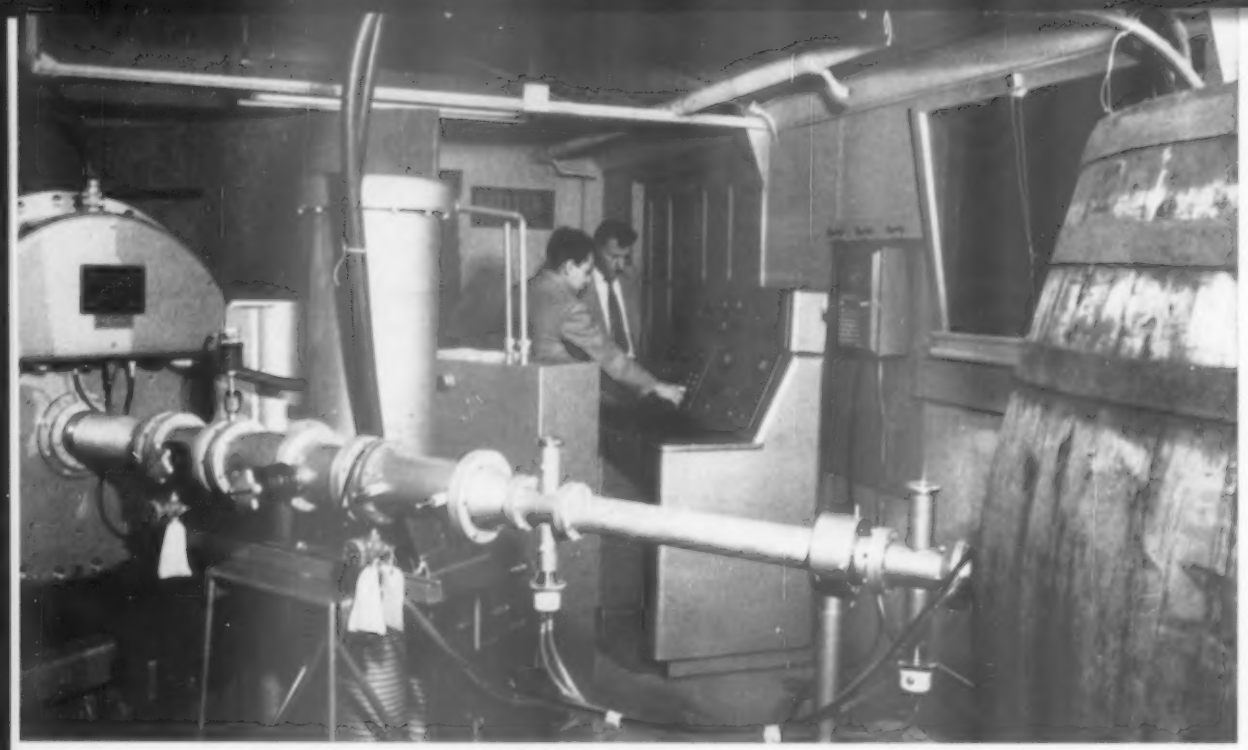


FIG. 1. Subcritical system installed in its pickle barrel (right) is shown with Van de Graaff generator (left) used as pulsed neutron source. Deuteron beam from Van de Graaff strikes Be target within the lattice

Subcritical Reactor in a Pickle Barrel—NYU's Training Tool

For $1,500 you can obtain a facility with uranium rods in water that constitutes a subcritical system with amplification factor of 6.7—sufficient for a wide range of teaching activities. With a pulsed source, reactor kinetics can be studied

By L. B. BORST
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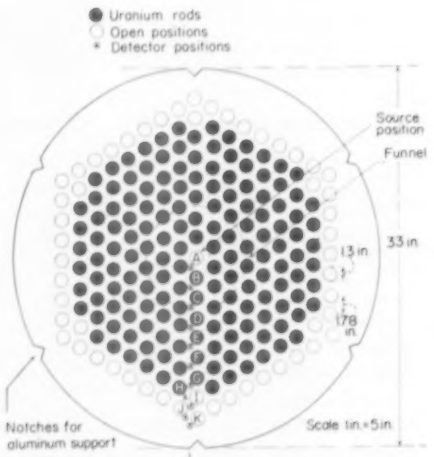

FIG. 2. Lattice of subcritical system

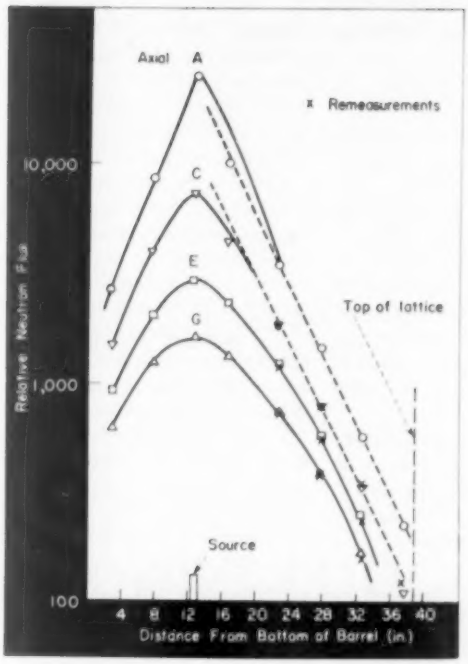

FIG. 3. Axial neutron distribution within the subcritical system. Letters refer to positions in Fig. 2

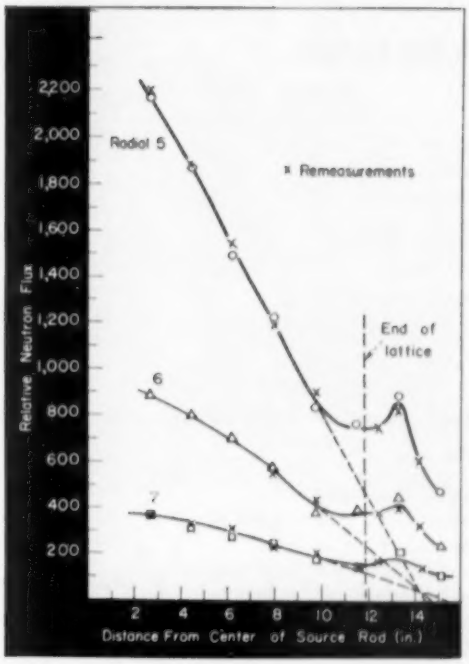

FIG. 4. Radial neutron distribution in subcritical system as measured with foils

SUBCRITICAL SYSTEMS, sometimes called exponential experiments, provide safe, inexpensive tools for teaching and simple experimentation. How New York University set up its subcritical "pickle barrel" (see Fig. 1) is described here.

Choosing the System

To study chain-reactions effectively, the lattice should amplify the source strength by a factor of more than 3. That is, for each neutron contributed by the source at least two should be contributed by the lattice. Since the neutron amplification is given by

$$S/S_0 = 1/(1 - k_{eff})$$

an equivalent requirement is that $k_{eff} > 0.67$. Of course, k_{eff} even closer to unity is preferable.

Aqueous solution. Preliminary calculations using reasonable quantities indicated that natural uranium dissolved in water (as nitrate or sulfate) gives an effective multiplication factor of 0.5. Thus, with such a system, the neutron amplification was limited to about a factor of two, and the chain reaction would only strongly perturb the neutron source.

Solid fuel. Feasible heterogeneous reacting systems using natural uranium are limited to water, heavy water, beryllium, and graphite. Water is best; all the other systems are either very large or very expensive.

The system H_2O-U was extensively studied at Oak Ridge in 1945 and again at Brookhaven in 1950–54. Detailed studies of various lattices gave evidence that the k_∞ of the optimum lattice was a few tenths per cent short of unity. Thus, a reasonable-sized uranium-water system can never become critical. Such a system

The High Cost of Reactors

Research reactors are high-cost laboratory tools by the standards of most university budgets. This high cost results from a complex of causes. Even a zero-power reactor or critical experiment has significant hazard. Thus an elaborate control system must be installed to maintain safe operating conditions. If these requirements are met, then the addition of a rudimentary cooling system converts it from a critical experiment to a research reactor. It then becomes a significant research tool of value to a diverse group of scientists. Research requirements tend to maximize flux, power, experimental facilities, and isolation. For these reasons, reactors for university use cost well above $100,000.

If a university installs such a high-cost device, research needs usually will encourage extended high-level operation. A reactor in steady-state maximum operation is no longer a useful instructional tool, and there always will be objections to taking it out of service for instructional purposes. Thus, a reactor is not likely to be a useful instructional device for training nuclear engineers.

The investment many universities can expend for instructional purposes must be commensurate with student fees. Therefore, a reactor can not be supported as a pedagogical instrument exclusively.

The realization of the foregoing problems led us to install a subcritical system.

With this budget . . .

	$1,500 (minimum)	$5,575 (optimum)
Container	*25*	*1,500*
Neutron source	*1,000*	*1,000*
Monitoring device		*1,000*
1 beta counter	*400*	*400*
Extra beta counter + 1 BF_3		*1,200*
Indium, cadmium	*75*	*75*

. . . You can buy a subcritical reactor with these specs . . .

Quantity of uranium metal	*4,000 lb*
Ratio V_{H_2O}/V_U	*1.5*
Size of uranium rods	*1.1 × 4 in.*
Length of lattice	*36 in.*
Diameter of lattice	*25 in.*
Reflector thickness	*8 in.*
Relaxation length	*14.0 cm*
Effective radius	*36 cm*
k_∞	*0.981*
k_{eff}	*0.85*
Amplification	*6.7*
Central flux (1 gm Ra-Be)	*$\sim 10^5$ n/cm²*

. . . And do these experiments . . .

Infinite multiplication factor, k_∞
Lattice amplification, $1/(1 - k_{eff})$
Reflector savings
Neutron distribution within lattice
Temperature coefficients
Control-rod effects
Conversion ratio, Pu atoms/fission
Cross sections
Spontaneous neutron generation
Fission-product studies

. . . Add a pulsed source and you can do these, too . . .

Delayed-neutron studies
Prompt reactor kinetics
Perturbed-lattice kinetics
Time-dependent neutron distribution
Cross-section measurements by oscillator techniques

needs no control system or shield since it is incapable of supporting a diverging chain reaction.

Obtaining the Unit

A request for the necessary uranium to achieve a $k_{eff} > 0.8$ was made to the Atomic Energy Commission.* The proposed system was set up and tested using Brookhaven facilities and materials (*1*). Figs. 2, 3, and 4 show the general arrangement of the system and flux traverses. From these studies k_∞ was predicted as 0.981 compared to Brookhaven's earlier estimate of 0.992 (*2*). For $k_\infty = 0.981$, k_{eff} was estimated as 0.85.

Upon receipt of AEC authorization, the pickle barrel with its 2 tons of uranium was moved to the NYU campus. It has been used for student instruction for the past semester.

Ra-Be Source

Initial studies were made using a 2-gm Ra-Be source on loan from AEC. Such a source can be a serious health hazard if unshielded. But the uranium lattice provides ample shielding—radiation at the exterior of the barrel is well within tolerance for slow and fast neutrons as well as gamma rays.

To obtain appropriate counting rates (using conventional indium-foil techniques), a source intensity of 10^7 n/sec is desirable. This corresponds to about 1 gm Ra-Be, 5 c Po-Be, or 75 gm Pu-Be. A source without intense gamma rays is desirable for student use.

Van de Graaff as Source

After initial installation of the pickle barrel, the High Voltage Engineering Corp. made available to NYU a Van de Graaff generator for use as a neutron source (see Fig. 1). This machine has a beam intensity of 50 μamp at a voltage of 2 Mv. Using deuterons on beryllium, the neutron source intensity is estimated to be 5×10^{10} n/sec. A re-entrant tube was inserted into the barrel (through the bung hole) to accommodate the accelerator target. As presently used, the deuterons impinge upon the beryllium target at the center of the uranium lattice, creating a source of 2–4-Mev neutrons.

Because of the increased source intensity it has been necessary to install extensive shielding around the barrel as well as around the generator itself, limiting access to the lattice.

Coupling the accelerator to a reactor produces a unique combination, opening the possibility of observations not easily achieved by the reactor alone. The fast kinetics of a reproducing system can be studied easily. An electrostatic deflector was installed so that the deuteron beam can be switched in 10 μsec from the Be target to a tantalum target outside the lattice.

Figure 5 shows the prompt transient in the reactor as measured by a BF_3 counter located outside the lattice. The initial period after beam deflection represents the transit time for neutrons to migrate through the lattice to the counter. Thereafter reactor response has a prompt period of 200 μsec.*

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2. H. Kouts, et al. in "Proceedings of the International Conference on the Peaceful Uses of Atomic Energy," vol. 5, p. 183 (United Nations, New York, 1956)

*These data were obtained through the assistance of C. Newstead and J. Ravets.

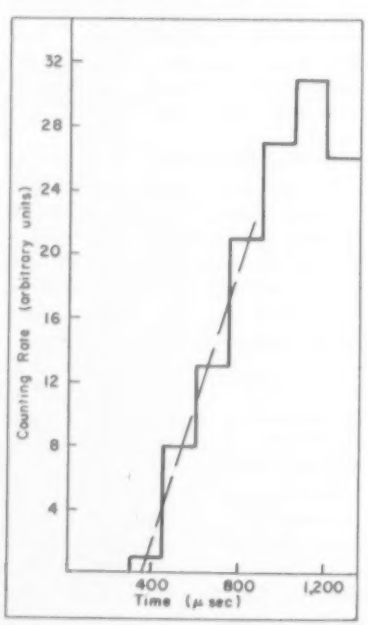


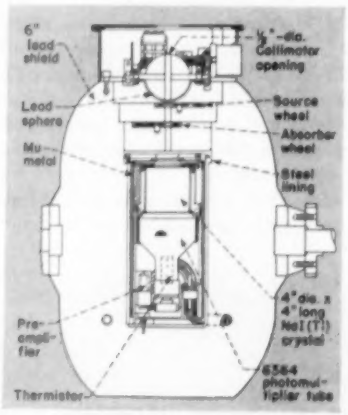
FIG. 5. Histogram of prompt neutron transient as observed by detector in reflector. Neutron source strength was raised from 10^4 n/sec (distributed through out lattice) to 5×10^{10} n/sec (at target) in 10 μsec

*The Atomic Energy Commission has established a program to encourage construction of subcritical reactors. Apply to the Division of Civilian Applications for the usual license to possess source or fissionable material and to the Division of Reactor Development for a loan of the necessary fuel. Local AEC Operations Offices negotiate the loan.

Mobile-laboratory truck is self-contained unit carrying electric generators, air conditioner, electronic test equipment. Shielded scintillation detector, mounted on rear of truck, is raised or lowered by manually operated winch; horizontal bearings permit positioning at any angle with vertical by motor drive. Face masks and clothing sealed with tape protect personnel in fallout field

Mobile Laboratory Measures Fallout Activity

By R. L. MATHER, R. A. TAYLOR, and C. S. COOK
U. S. Naval Radiological Defense Laboratory, San Francisco, California



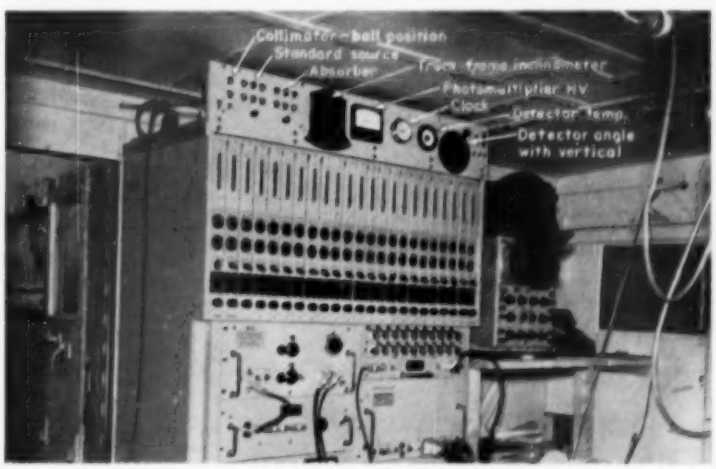
Scintillation detection unit. Rotating lead sphere closes collimation hole for background count; calibration is made by rotating standard source on wheel into collimator channel; second wheel contains foils for absorption measurements—these operations can be done remotely from within truck

To GATHER DATA on radioactive fallout from nuclear weapons, NRDL has converted a military truck into a mobile laboratory. The best source of this data is the weapons-test series. Because of the nature of the tests—isolated area, large variety of experimental conditions, short-lived fallout decay—this elaborate unit is necessary.

The purpose of the truck laboratory is to make gamma spectral measurements. The truck is driven into a moderately contaminated fallout region and located by transit measurements. The data is recorded by photographing the scaling units and monitoring panel. The film record is developed at the base camp and returned to the laboratory for data analysis.

* * *

In addition to the authors, other members of the laboratory staff contributing to this work were W. E. Kreger, A. J. Hodges, R. F. Johnson, L. A. Webb, F. M. Tomnovec, R. F. Ehat, and H. L. Johnston.



Truck interior. Electronic equipment includes spectrometer, linear amplifier, 20-channel pulse sorter, and 23 plug-in scaling strips (including total, surplus, and elapsed time)

FIG. 1. Smoke-generator on 300-foot tower is used by NYU meteorologists in 1-yr weather study of Indian Point site's micrometeorology

PROGRESS REPORT

Indian Point Plant Enters Construction Phase

Con Ed's project, holder of AEC's construction permit No. 1 for power reactors, goes from drawing boards to order books

THE INDIAN POINT nuclear steam electric generating station of Consolidated Edison, the electric utility that supplies New York City, has begun moving from engineers' drawing boards into salesmen's order books.

July 1 was the official date of the order for the reactor, which Babcock & Wilcox will manufacture under the terms of a contract signed in March, 1955. Fifty Con Edison employees and 85 Babcock & Wilcox employees have been engaged in various aspects of the design work. Generally, the utility company has stuck to the conventional parts of the plant while B&W is concerning itself with the nuclear system.

As for hardware, Con Edison has awarded a contract to Westinghouse Electric to design and construct a turbogenerator for $8-million. The machine will have a nameplate rating of 250 Mw, run at 1,800 rpm with steam conditions at throttle 1,000° F and 335 psig. It will be a tandem compound condensing unit, with double flow in high-pressure and low-pressure cylinders. Delivery is scheduled for spring of 1959.

Award of a contract for the oil-fired superheater is expected to be made

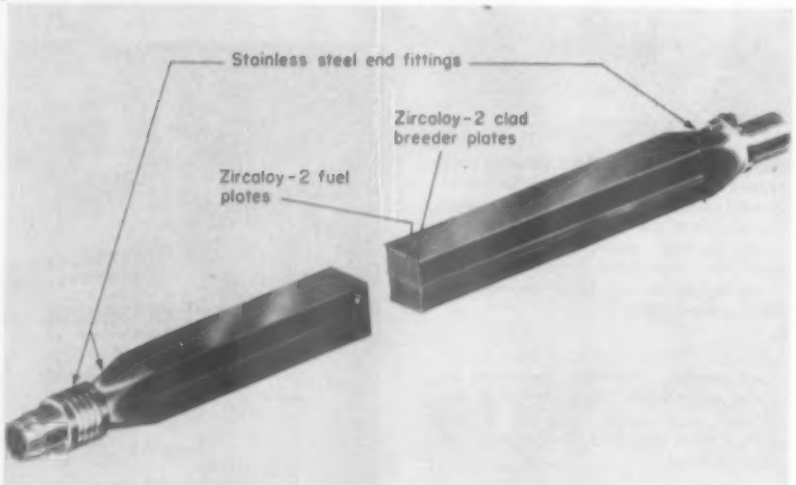


FIG. 2. Proposed fuel-element design uses Zircaloy-2-clad breeder plates sandwiched between Zircaloy-2 fuel plates 6 ft 1 in. long. Element over-all is 8 ft. 4.5 in. × 5.856 in. square

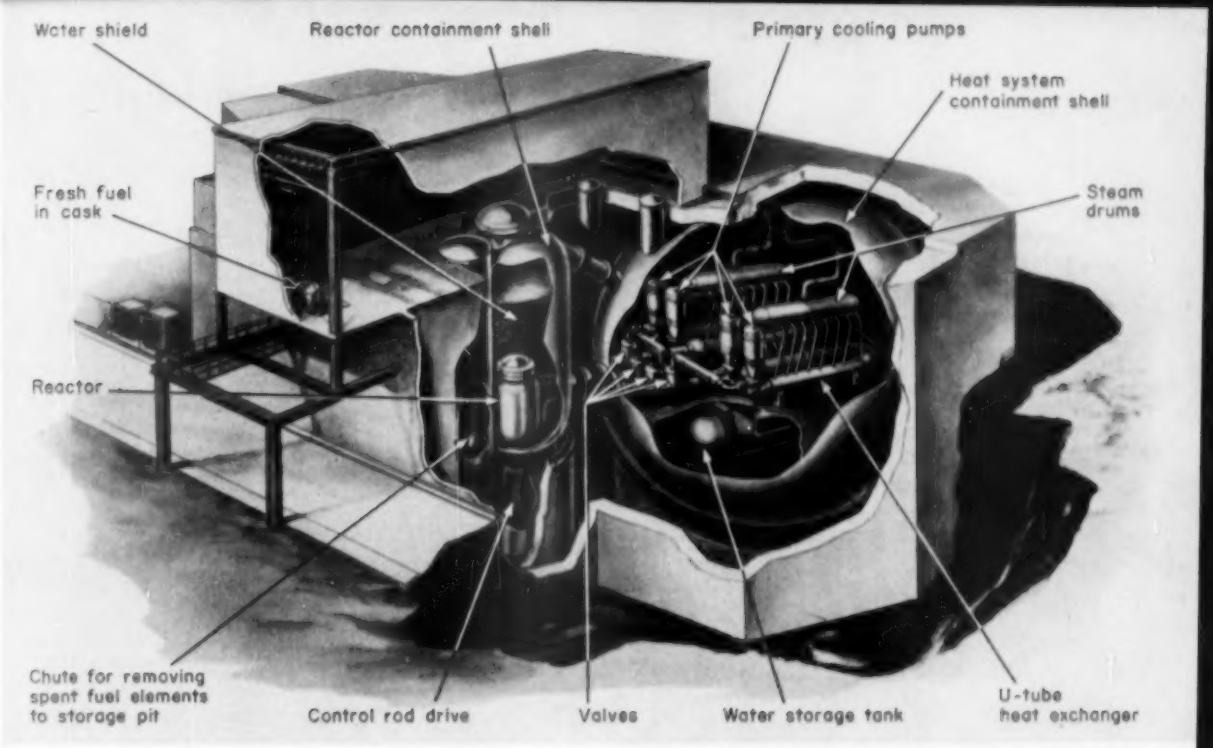


FIG. 3. A recent cutaway sketch of nuclear steam-generating portion of Indian Point plant shows how reactor is connected to one of two steam system vapor containers, each holding two U-tube heat exchangers. Second steam system container is hidden behind reactor container with only access hatch showing. Space between reactor pressure vessel and its container is water-filled for shielding

shortly; B&W, Foster Wheeler and Combustion Engineering are known to be bidding for it.

The task of clearing the site, grading it, and building roads will begin October 1.

By the end of 1956, Con Edison either directly or through B&W will have spent or committed about $21-million on the Indian Point project. The remainder of the plant's estimated $55-million cost will be spent about uniformly during the years 1957–9 on purchase of minor equipment, for materials, and for field construction. It is planned to have the reactor critical by December 1, 1959, and at full power operation by June 1, 1960.

Started in 1954

Con Edison moved into the nuclear field shortly after passage of the Atomic Energy Act of 1954 with the acquisition of a 350-acre tract at Indian Point in upper Westchester County. The company had participated in the Dow Chemical-Detroit Edison study group (now Atomic Power Development Associates, Inc.) since 1952, and had received its real nuclear christening early in the Manhattan Project when it lent several employees to the government to struggle with construction and power supply problems at various sites.

On December 7, 1954, Con Edison notified AEC that it was launching talks with various manufacturers in the nucleonics field. From several proposals made to it, the company selected a pressurized-water enriched-uranium thorium-converter reactor. On March 22, 1955, the company applied to AEC for the necessary permits to construct and operate the nuclear facility at Indian Point. No government help was requested. Vitro Corporation of America was engaged as nuclear consultants.

Design work on the reactor continued while all the "-logical" studies connected with the license application were made: seismological, hydrological, geological and meteorological. Father J. Joseph Lynch, head of Fordham University's Seismic Laboratory, reported the area should be as free of earthquakes as any known area in the world. Carl Kennison, consulting engineer and chief engineer of the New York Board of Water Supply, stated that with safety features of the plant, as reported to him, there appeared no possibility of radiocontamination of the Hudson River or of the public water supplies in the area. Sidney Paige, retired professor of geology at Columbia University, concluded that rock at the Indian Point site, properly grouted, would support any structure that man might build.

Micrometeorology Studied

A research team from New York University led by Ben Davidson has been gathering and analyzing data on the micrometeorology of the area since April, 1955. While their studies are not yet complete, Davidson has found some of the typical up and down wind features that are expected in a valley but few of the typical cross-valley features. The wind vector at Indian Point makes a 360° rotation.

These data were reported to AEC and its Advisory Committee on Reactor Safeguards during 1955. Several meetings were held with ACRS and at least one physical-layout change resulted from these meetings. The original proposal had called for four steam generators to be located in four separate horizontal containment cylinders and connected to the reactor containment vessel by means of piping carrying the primary coolant water.

Instead of this arrangement, the exposed piping was eliminated by substituting two spheres for the four cylinders. The four steam generators are to be located two and two inside

the spheres, which are joined to the reactor containment vertical cylinder by expansion joints. The 70-ft spheres will be of 1¼-in. steel plate, capable of containing all the steam that might be created by a major rupture of the primary system.

A formal presentation to ACRS was made January 4, 1956. This hearing, together with information submitted directly to AEC's Division of Civilian Application, formed the basis for AEC's action May 4, when it issued construction permit CPPR-1 for the Indian Point plant.

Several months prior to the hearing, B&W initiated detail design work to optimize core components, the heat balance of the system, water-purification equipment, pumps, valves, control-rod drives, mechanical handling equipment, pressurizer, and the arrangement of the containment and fuel-element cooling components. This work has been continued with increasing intensity and is expected to continue well into 1958.

The reactor controls will be so arranged that constant steam pressure can be maintained as load is varied; in other words, the reactor will be controlled for constant steam pressure rather than constant reactor temperature. This has the great advantage of permitting the plant to be more responsive to load demand and at the same time safer. When a reactor is controlled for constant coolant temperature—as have been most reactors to date, if the load falls off, the turbine throttle starts to close and pressure goes up—just when it is not needed. On the other hand, more power requires a greater volume of steam: if load demand goes up, the throttle opens and the pressure—which would tend to drop—must be raised to be held constant; therefore steam generation must be increased. But in a reactor with a negative temperature coefficient, the natural tendency works in just the wrong direction: it is a drop in pressure that increases heat generation.

At Indian Point, a pressure gauge will be located on the steam side; as the throttle starts to close and the pressure goes up, an automatic mechanism will begin to push the rods back into the reactor without waiting for the temperature to rise.

Core Specifications

The reactor core is a right cylinder about 6 ft high and about 6 ft in mean diameter. It is made up of more than 100 replaceable fuel elements, each of which is square in cross section and contains alternate fuel and fertile plates separated by coolant channels. Fuel plates are 0.060 in. thick and made up of highly-enriched uranium-Zircaloy-2 "meat" clad with Zircaloy-2. Fertile plates are 0.080 in. thick and consists of thorium "meat" clad with Zircaloy-2. Coolant channels are 0.100 in. thick.

With about 55% of the core volume filled with water and an inventory of about 8,275 kg of thorium, about 275 kg of fully enriched U^{235} provide sufficient excess fuel to accommodate the various reactivity changes. With this loading the initial thermal-neutron flux at full power is about 8×10^{13} n/cm²/sec. Average heat flux for full-power operation of a new core is about 167,000 Btu/ft²/hr. This is reduced somewhat as the production of heat is spread to the thorium plates and, since no more than one-third of the core will be replaced at any one time, will never exceed initial value.

Separation of the fissionable and fertile material makes possible fairly lengthy irradiation of the fuel elements. With the passage of time, an appreciable portion of the U^{233} produced in the thorium is consumed *in situ* and contributes to the reactivity of the core in a favorable way.

Proper operation of this reactor requires an excess of reactivity over the cold, clean core so as to compensate for the effects of: (a) increase in moderator (water) temperature, (b) buildup of equilibrium poisons (Xe^{135} and Sm^{149}), (c) burnout of fuel and buildup of higher isotopes, and (d) short-time shutdown buildup of Xe^{135}. This excess reactivity is balanced out as required by 19 individually-driven cross-shaped boron-steel control rods that ride into the reactor from above but are actuated from below by means of zirconium extension pieces. The drive mechanisms are located in a sealed housing attached to the bottom of the reactor containment vessel. The effective part of each rod assembly is about 5½ ft long.

The proposed rod pattern is a central regulating rod surrounded by 18 shim rods in two concentric rings. Size and location of the rods will provide the required excess reactivity plus about 5% extra shutdown Δk below the cold, clean condition, to provide for suitable sensitivity to regulating-rod movement, and to obtain some degree of flux uniformity. Rod removal rates will be limited to insure a safe maximum rate of reactivity change. An additional safeguard is provided by the negative temperature coefficient of 1.5×10^{-4} Δk/°F at operating temperature.

Control-rod drives will probably be of the hydraulic type, with scram action initiated by a hydraulic unloading valve. Scram force will be provided by the pressure in the reactor acting on the piston area of the extension shaft. This may be augmented by spring force or by a hydraulic accumulator.

The core will be housed in a heavy pressure vessel about 23 ft high and 10 ft in diameter with a wall thickness of nearly 6 in. The vessel is to be made of carbon steel clad on the inside with stainless. The pressure vessel is in turn set in a large containment tank, approximately 50 × 20 ft, made of carbon steel. The containment

Estimated Annual Costs at Indian Point

Gross heat capacity, reactor		500 Mw
Gross electric capacity, reactor		140
" " " superheater		96
" " " total		236
Net electric capacity, reactor		130
" " " superheater		89
" " " total		219
Annual net production at 80% load factor, reactor		910 MMw
" " " " " " " superheater		623
" " " " " " " total		1,533
Annual costs	*Amount ($10)*[6]	*¢/kwh*
Fixed charges—$55-million @ 13.5%	7.43	0.485
Fuel—nuclear and oil	4.65	0.303
Operation and maintenance	1.50	0.100
Total	13.58	0.888

tank will be filled with water to serve as a heat barrier and neutron shield.

During full-power operation the reactor will produce neutrons with energies ranging from thermal to greater than 10 Mev and gamma rays from zero to 8 Mev. The water layer will attenuate the fast-neutron flux to a level low enough to prevent neutron activation of surrounding equipment, attenuate both primary and secondary gamma-ray intensity to a low level compared with primary coolant activation, and attenuate core and pressure-vessel decay gammas to a level low enough to permit access to the plant shortly after shutdown.

The water layer over the reactor is sufficient to reduce the gamma-ray dose rate to below tolerance (7.5 mr/hr) above the containment tank during full power, and to permit removal of the pressure-vessel head without additional shielding.

Design tolerance outside the biological shield is 0.75 mr/hr at the accessible boundary of the installation. Within the boundary of the installation, where 40-hr access is required, the design tolerance is ten times greater, or 7.5 mr/hr. These specifications agree with the New York State Labor Department's Industrial Code No. 38 and with the AEC's Regulation 10 CFR, Part 20.

Under normal conditions, 120,000 gpm of coolant are passed through this reactor—mostly through the fuel element coolant channels, although significant diversions are made for the control rods, the reflector, and the thermal shields. The coolant flow is upward, single-pass, from four 20½-in. inlet nozzles in the lower section of the vessel.

The coolant pressure will be maintained at 1,500 psia, enough to prevent boiling at the upper ends of the coolant channels where the temperature is highest. The coolant temperature is limited by a maximum fuel-plate surface temperature of 600° F. Mean reactor outlet temperature is 510° F and mean reactor inlet temperature is 480° F. This is sufficient ΔT for generation of the rated heat power.

The primary coolant system consists essentially of four loops operating in parallel, each transferring 25% of the total power generated by fission in the reactor core to the steam system. Each loop comprises a boiler, two 15,000-gpm pumps with associated check valves, 24-in. stainless steel pipe, and two 24-in. remotely operated stop-valves to permit isolation of the loop.

Each boiler consists of two major components: an evaporator section and a separate steam drum. The evaporator section consists of U-shaped stainless steel tubes, the ends of which are welded into heavy tube sheets, enclosed in a U-shaped carbon steel shell. The primary coolant flows through the tubes.

Steam Conditions

Steam is generated in water surrounding the tubes and flows up to the steam drum, which is sufficiently elevated to create natural circulation through riser pipes. With feedwater at 332° F, each of the four boilers will generate about 472,000 lb of saturated steam per hour at 420 psia, making the total output 500 Mw of heat.

A pressurizer is located at the high point of the primary system. Steam created by cartridge-type heaters will generate a steam head in the upper part of the pressurizer. The heaters are capable of bringing the system from atmospheric pressure to 1,500 psia in about four hours. The pressurizer is sized to accommodate the contraction and expansion of the primary coolant due to changes in the steam demand. It is equipped with a spray nozzle connected with the reactor for additional pressure control and possible degasification, and contains a water-level control device with high and low limit indicators.

During shutdown, heat will continue to be generated in the fuel elements of the reactor by radioactive decay of the irradiated material. Normal shutdown procedures are such that the elements are cooled by forced convection until they are able to be cooled by natural circulation. In the event of power failure, emergency drives attached to one main cooling pump in each loop will supply adequate circulation during the danger period.

Superheater

The heat produced by the reactor would result in electrical generation of 140 Mw. Since present temperature limitations of reactors result in saturated steam of relatively low pressure, and thus temperature, as compared to modern steam plants, Con Edison decided to investigate the economics of superheating the steam generated by the reactor before using it in the turbogenerator. The cost, capacity, and plant heat-rate were calculated for plants using saturated steam and those using superheated steam at 860° F, 1,000° F and 1,050° F at the throttle.

The temperature selected on the basis of economics was 1,000° F. Steam pressure at the throttle will be 370 psia because of the pressure drop in the superheater.

By adding superheat to the plant cycle, capacity is increased from 140 to 236 Mw. Costs are reduced from $322/kw for a plant using only nuclear fuel to $233/kw for a plant using a combination of a nuclear boiler and a separate oil-fired superheater.

Production costs, with a plant load factor of 80% and fixed charges at 13.5%, are estimated at 0.888 cents per net kwh. This includes a conservative allowance of 1 mill/kwh for operation and maintenance exclusive of fuel, although comparable charges at Con Edison's newest conventional plant are running 0.5 mill/kwh.

In addition to the design work currently under way, a full-scale core of the Indian Point design, fully loaded with fuel, will be constructed at B&W's Lynchburg, Va., test facility this summer to: (a) check critical mass and neutron spectrum calculations, (b) determine control-rod worth and power distribution, (c) measure thermal and resonance capture of neutrons in thorium, U^{235} and U^{233}, (d) measure the uniform temperature coefficient of reactivity, the Doppler coefficient of reactivity, and the void coefficient as a function of position in the core, and (e) make danger-coefficient measurements with actual reactor fuel elements.

Thorium Supply

While Con Edison has arranged with AEC for the source and fertile material for the Lynchburg critical test core, it has launched a series of discussions with suppliers looking toward a supply of thorium for the reactor from non-government sources. Expressions of interest have been secured from Sylvania Electric Products, Vitro Corporation of America, Horizons, Inc., and National Research Corporation.

The company expects to negotiate on the reprocessing of spent fuel elements

(Continued on p. 117)

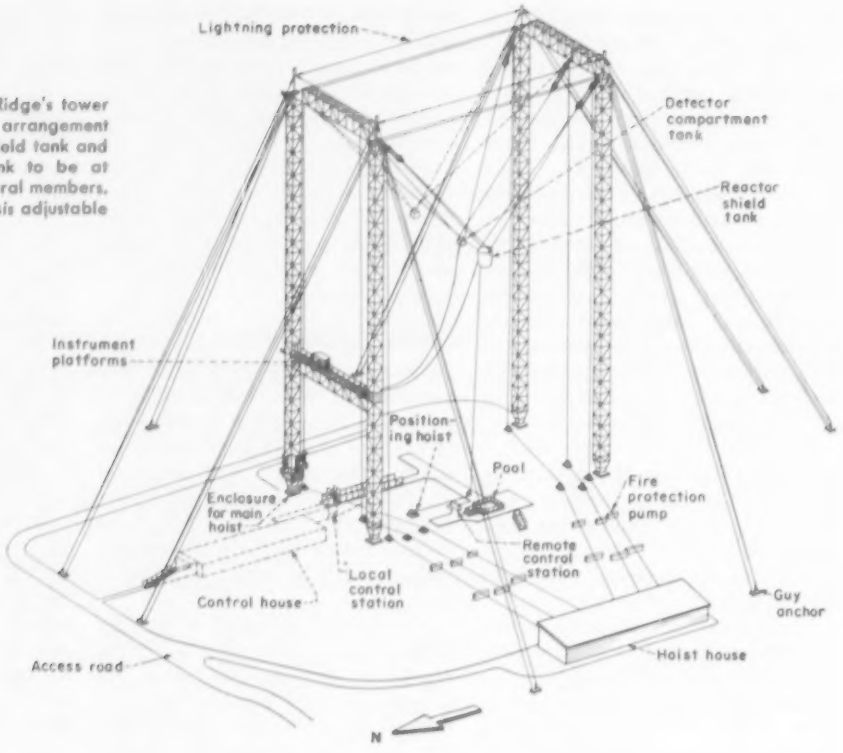


FIG. 1. Layout of Oak Ridge's tower shielding facility shows arrangement permitting both reactor shield tank and detector compartment tank to be at least 100 ft from all structural members. Distance between two tanksis adjustable from 35 to 100 ft

Who's Who in the Aircraft

ALTHOUGH THE AIRCRAFT nuclear propulsion program is generally accepted as being the second most secret project in the country—yielding in this respect only to the intercontinental ballistics missile project—there have been unmistakable signs in the news the last few months that the program has finally gone into high gear. Several companies are building huge research and development facilities; five new reactors are being added to the four already in use to further the program. No one in authority has yet said it for the open record, but unofficially it is still being hinted that 1958 may see the first airplane flying on nuclear power.

The early vicissitudes of the nuclear plane program can easily be read between the lines of the curt, spare paragraphs that refer fleetingly to ANP in the Atomic Energy Commission's semiannual reports. These go back through the whole history of AEC, for nuclear plane propulsion is one of the oldest nonweapons projects in the entire field: it dates back to 1946, to the pre-AEC days of the Manhattan District. At that time the then Army Air Force signed a contract with Fairchild Engine & Airplane Corp. as prime contractor for studies in this field. And the Manhattan District made space and technical services available at Oak Ridge. But there was fierce opposition. A technical review board—the Lexington Project—was named in the expectation it would scuttle the program; instead, the scientists and engineers vindicated faith in the potential of nuclear flight. The Navy Bureau of Aeronautics and NACA—the National Advisory Committee for Aeronautics—joined in the work in 1949. At that time the major emphasis was on shield measurements and on development of light materials capable of resisting high temperatures and intense radiation.

On April 30, 1951, AEC—which had taken over some of the Air Force's share of research—announced that the theoretical feasibility of nuclear-powered flight had been established. About that time Fairchild's contract was terminated for the work in the NEPA (Nuclear Energy for Propulsion of Aircraft) division at Oak Ridge. Instead, AEC negotiated a contract with General Electric's aircraft gas turbine division at Cincinnati for aircraft reactor design and development. Later that year Consolidated Vultee Aircraft Corp. of Fort Worth (now Convair division of General Dynamics Corp.) began work on an airframe, and Pratt & Whitney division of United Aircraft, East Hartford, Conn., started a new plane engine program. In 1952 General Electric built two new facilities, one near Cincinnati, the other at the National Reactor Testing Station in the southern Idaho desert.

But despite the facilities, progress lagged. In retrospect, some of the members of the Joint Congressional

FIG. 2. Aerial view from one of four 315-ft-high 9-ft-square steel lattice columns shows pool where reactor is lowered for storage, shield changing

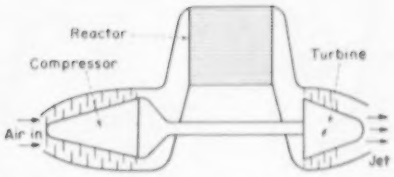


FIG. 3. Schematic of a possible direct-cycle air-cooled nuclear plane engine

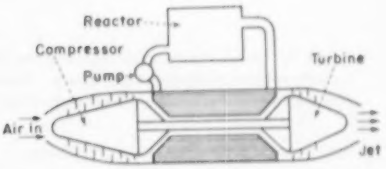


FIG. 4. Indirect-cycle liquid-cooled system. Whichever type is used, minimum parameters have been estimated at 30,000 hp, 100 tons total plane weight, of which nearly half is shielding

Nuclear Program

By JOHN E. KENTON
News Editor
Nucleonics

Committee on Atomic Energy have expressed regret that the nuclear plane project did not have a Rickover of its own to drive it through or over obstacles. In the summer of 1953 the program was "reoriented"; abandoning the firm target date of 1958 by which time it had until then been intended to get a nuclear plane into the air, AEC placed primary emphasis instead on a general research program on the problem of nuclear flight propulsion.

The summer of 1954 marked completion of a small tower shielding facility at Oak Ridge, and early in 1956 the Air Force and Convair announced that a test reactor had been installed in a conventionally-propelled B-36 for airborne shielding studies. Tip-off that the program was finally rolling came in April this year when the Air Force announced it would build a long-planned airstrip almost three miles long at NRTS. Since then, announcements of expansion of the program have come in almost unbroken succession.

The over-all picture of the distribution of nuclear plane work today, then, looks something like this:

National Laboratories

At Oak Ridge National Laboratory, the most spectacular facility is the $2-million tower shielding apparatus. This consists of four 324-foot steel towers from which protective shielding for a plane crew and a test reactor with its own shielding can be suspended well above the ground to simulate shielding conditions in an airplane in flight.

The University of California Radiation Laboratory at Livermore, Calif., also is working in the fields of heat transfer, pressure, and materials. Although some experimental work is involved, most of it is analytical.

The Air Force is installing a test facility at the Wright Air Development Center, Dayton, Ohio, construction of which alone will cost $7.5 million exclusive of equipment. Main feature of this center, to be known as the Air Force Nuclear Engineering Test Facility, will be a 10-Mw water-moderated and -cooled research reactor similar to MTR but with a 125,000-gal pool adjacent to one side. In addition there will be a high-level-radiation laboratory, a waste storage and treatment plant, and an engineering lab.

Industry Contractors

Propulsion units. GE, Pratt & Whitney and Curtiss Wright are the three major contractors.

GE is doing criticality and other nuclear calculations at the big laboratory it built in 1952 at Evendale, just north of Cincinnati, where air reactor research is centered. It has set up a critical assembly there for this work. And at Arco, GE operates a Government-financed installation that cost $33-million when it was built in 1952;

FIG. 5. Map shows major installations where work is being carried out on aircraft nuclear propulsion program. Dawsonville, Quehanna, and Dayton are newest facilities; construction is underway on first two, third is now out for bids

it has since been expanded considerably. Here GE does heat transfer experiments with an air-cooled water-moderated thermal neutron reactor for test-stand operation. Recently some of the fuel elements melted down during transient tests—hardly surprising considering the extreme temperatures to which they are subjected; when working at new frontiers of temperature, it is to be expected that some elements will not stand up: the aim is to find those that will. GE has a design for a reactor—also for test stand operation—whose UO_2 fuel plates sandwiched in stainless steel are intended to operate at 1,800° F maximum. These high temperatures together with light weight and relatively low pressure are designed to counterbalance low heat-transfer coefficients, induced radioactivity in cooling air (requiring the turbines to operate radioactively hot), high pumping costs for circulating air.

Pratt & Whitney operates for the Defense Department a $10-million laboratory at Middletown, Conn., called CANEL—Connecticut Aircraft Nuclear Engine Laboratory. The firm is also doing some work on the project with the water boiler at Livermore.

Curtiss Wright has an AEC contract for nuclear engine work involving calculations with electronic computers. Its main effort, located until now at Woodbridge, N. J., is being moved to a big new reactor-equipped laboratory and development center Curtiss is building on an 80-mi² site at Quehanna in north central Pennsylvania.

Airframe. Here Convair and Lockheed are carrying the ball.

Convair has just signed a new AEC contract under which it will turn from blueprints to hardware, will add a third reactor to the two already in use at Fort Worth. The first was a small machine suspended from the boom of a mobile crane for shielding experiments analogous to those carried out at the Oak Ridge tower facility. The second is the one installed in a B-36 to test various shielding configurations, to investigate shielding effects of radiation on aircraft materials and systems, and to develop airborne nuclear instrumentation. The new reactor, which will develop 10 Mw (heat), will be used for work on radiation effects.

Lockheed's nuclear aircraft preliminary design study has just been transferred from its California division at Burbank to the Georgia division at Marietta; and a new, $100-million test facility is under construction in mountain country at Dawsonville, Ga., 60 mi north of Atlanta and 50 from Marietta. The Dawsonville labs will be backed up by two 10-Mw (heat) reactors, one atop a tower for shielding studies, the other for tests of radiation effects. Both are to be built by GE. This facility will be Government-owned and -financed; Lockheed contributed the 10,000 acres which it bought for $500,000 and deeded to the Government for $1. Dawsonville will be the research, development and test center, Marietta eventually the construction and manufacturing center. A scientific and engineering complex is now being built at the latter to house the work moving from Burbank.

Other Work

The Navy moved into an active role within the past year when it gave a contract to Allison division of General Motors for studies on a nuclear-propelled-seaplane engine. However insofar as the organization charts go, this work is also directed out of AEC's Aircraft Reactors Branch, headed by Air Force Brig. Gen. Donald J. Keirn, who exercises technical supervision over all Federal nuclear flight programs.

Finally, at least two private airplane manufacturers—Boeing and Bell—are known to be conducting nuclear plane studies on their own, independent of the Government's ANP program.

It is likely that the early-model nuclear planes will be dual-propulsion types, with conventional engines to be used at take-off and landing, and the reactor operating only while the plane is in flight.

Nuclear airplanes "could be, but would not necessarily be" faster than conventional types, Air Force Secretary Donald Quarles told a Congressional committee recently. Their tremendous advantage, of course, would be their practically unlimited range. By the same token, since unlimited range regardless of cost is a desideratum only for military purposes but not for commercial operations, experts are agreed that nuclear airliners are a long way over the horizon.

However, the nuclear military plane is now clearly in sight. "We've got the project off the ground," Senator Henry M. Jackson (Dem., Wash.), head of the Joint Congressional Atomic Energy Committee's military applications subcommittee, told NUCLEONICS "There has been very substantial improvement and the program is now vastly accelerated over the previous slow rate."

And Rep. Melvin Price (Dem., Ill.), head of the same committee's research and development sub-group, adds, "Every member of this Committee is disappointed that we haven't a plane in the air now—but I don't say this is for lack of effort. The Committee has been prodding steadily on this for 10 years, and it has been disappointing to see the stop-and-go nature that characterized the program in its early days. But now it is going ahead."

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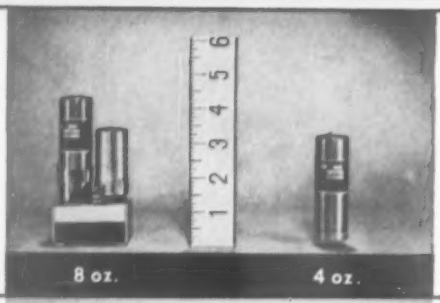

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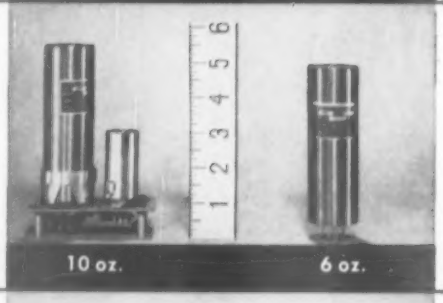

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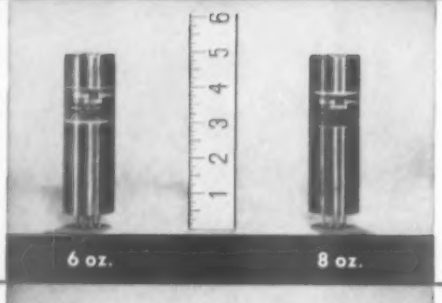

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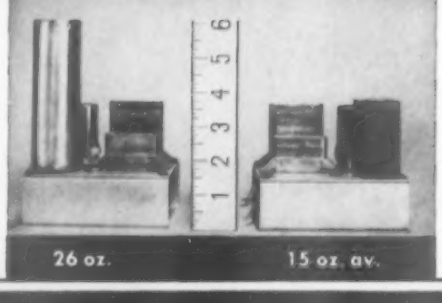

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Simple, Inexpensive Device Checks G-M Tube Operation

By F. E. ARMSTRONG
Bureau of Mines, U. S. Department of the Interior
Petroleum Experiment Station, Bartlesville, Oklahoma

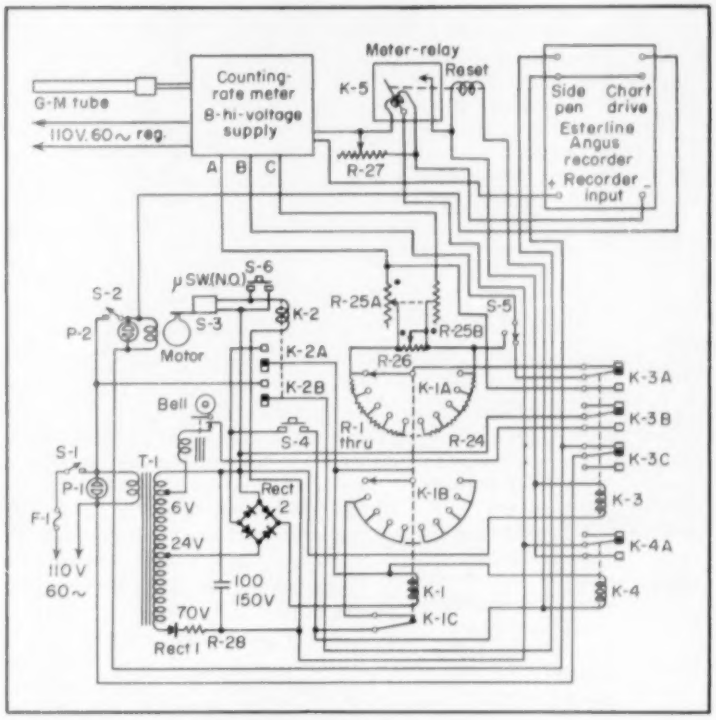

FIG. 1. Circuit of G-M tube checking device

FIG. 2. Assembled apparatus includes recorder, automatic-stepping-switch control unit, and counting-rate meter

The operational characteristics of conventional Geiger-Mueller (G-M) tubes change continuously during their useful lives. For accurate and reproducible counting, determination of threshold voltage of the tube and the slope and length of the plateau at frequent intervals is necessary. This is particularly true with organically quenched tubes.

Plateau determination in the small radiochemical laboratory usually entails making a large number of counts with a scaler and increasing the voltage in small increments after each count. The process is tedious, time consuming, and often inaccurate because of the difficulty of making small, precise voltage adjustments using a high-range voltmeter.

The test instrument described herein is inexpensive to construct, is fully automatic in operation, and gives much more accurate results than the usual manual methods.

This device was designed for use with a standard commercial counting-rate meter (Berkeley Model 2810) and a 1-milliampere, moving-coil-type, strip-chart recorder (Esterline-Angus).

Any stable counting-rate meter having provision for use with a recorder might be used. The high-voltage supply of the counting-rate meter must be regulated and must have a voltage divider across the reference-voltage source for adjusting the high voltage. In the Berkeley Model 2810, as in most similar instruments, this control is a small potentiometer mounted on the front panel. The three leads to this potentiometer are the only extra connections made to the counting-rate meter.

A three-pole double-throw switch makes a convenient changeover device if there is room to mount it on the counting-rate-meter chassis. The chassis of the Berkeley instrument we used was so crowded that it was necessary to bring out the 6 leads (3 leads to

and 3 leads from the potentiometer) in a short cable terminated in a 6-prong Jones connector. A shorting plug connected the leads for normal operation.

Figure 1 is a circuit diagram of the tube checker. Figure 2 is a photograph of the apparatus assembled for operation. Lead A is the low voltage or ground, and lead C is the high-voltage end of the high-voltage control potentiometer. Lead B is the tap or control lead.

The voltage divider in the Berkeley instrument is a 250 k-ohm unit. The voltage divider in the automatic control unit consists of a 100,000-ohm dual potentiometer (R-25) and a 25-position 2-bank stepping switch (K-1). Resistors R-1 through R-24 are mounted on one terminal bank, thereby providing effectively a tapped 52,800-ohm resistor. A 250,000-ohm variable resistor (R-26) connected in shunt with the stepping-switch divider allows the effective resistance of the tapped portion of the divider to be adjusted between the limits of zero and about 43,000 ohms. This maximum resistance is 30% of the total divider resistance or, in terms of high-voltage output from the power supply, 750 volts of a total of 2,500 volts. As the stepping switch (k-1) has 25 positions, a maximum increment of 30 volts is allowed. The total divider resistance is 143,000 ohms, which is about 100,000 ohms less than that of the original circuit. This decrease in total resistance, of course, increases the current demand on the reference-voltage source; however, the increase is slight and the stability and linearity of the system are improved.

The stepping switch was obtained as war-surplus material, as were many of the other components of the device, and was designed for 48-volt, d-c operation. Satisfactory operation was obtained from a 24-volt supply, however, and the lower-voltage dry-disk rectifier was less expensive. The second set of contacts on the stepping relay were arranged to return the relay contacts to the low-voltage position when the reset button is pressed.

Operation

The first step in preparing the unit for operation after making the necessary interconnections between the counting-rate meter, the recorder, and the control unit is to adjust the voltage-divider resistors for the desired sweep-voltage level and range.

The voltage-stepping increment is one-twenty-fifth of the total range and usually is chosen to give whole units on the recorder chart, such as 2, 5, 10 or 20 volts with each step, depending on the desired range. With resistor R-26 set at the minimum value (zero sweep range), dual potentiometer R-25 is adjusted to give a reading on the high-voltage meter equal to the mid-range voltage. Resistor R-26 then is adjusted until the reading on the meter is equal to the lower limit of the desired sweep range. Switch S-5 allows a check of the upper voltage limit at this time. Since the two controls (R-25 and R-26) have a slight interaction, it is necessary to check the high and low limits several times by switching back and forth from the high to the low side of the divider while adjusting the range.

The G-M tube to be checked then is attached to the counting-rate meter input and the voltage is stepped up manually, using switch S-6, a few steps above the threshold voltage to establish a counting rate. A radioactive source is positioned to give a counting rate high enough to provide good statistical accuracy. This rate usually is 5,000–10,000 cpm with a half-time constant of 20 sec.

The meter relay then is set to trip at a further increase of 10–15% in counting rate. In the instrument described, a Weston fixed-contact meter was used, necessitating the use of a shunt across the moving coil to control the range. A meter with adjustable contacts would simplify this adjustment. A microswitch (S-3) driven by a cam on a small, synchronous timing motor, causes the stepping switch to advance one contact a minute. Switch S-2 energizes the timing motor and starts the recorder chart drive.

A side pen on the recorder puts a mark on the chart each time the stepping switch is pulsed, thereby drawing a synchronized voltage scale on the record.

When the counting-rate meter output to the recorder increases beyond the preset limit, the meter-relay contacts close, energizing relay K-3. This transfers the high-voltage control tap to the low-voltage side of the divider resistors, thus lowering the high-voltage output below the threshold voltage of the tube. At the same time it turns off the recorder-paper drive and rings a bell to summon the operator. The operator pushes the reset button, which resets the contact meter and homes the relay to the low-voltage position. Relay K-4 holds relay K-3 energized during the reset period. The operator then turns off the timing motor drive with switch S-2, removes the tube just checked, and inserts the next one. Closing S-2 starts the unit through the cycle again.

Component Parts

R-1 to R-24	Resistors, 2,200-ohm, ½-watt, 5% carbon, insulated
R-25	Dual potentiometer, 100 k-ohms each section, linear-taper, carbon, 3-watt
R-26	Potentiometer, 250 k-ohm, linear-taper, carbon, 3-watt
R-27	Potentiometer, WW, meter-shunt, value to suit meter
R-28	Resistor, 56-ohm, ½-watt, carbon, insulated
K-1	Stepping relay, 25-position, 2-bank, 24–48 volt coil, with interrupting auxiliary contacts
K-2	Relay, telephone-type, plate, DPDT contacts, 7,500-ohm coil
K-3	Relay, telephone-type, plate, 3PDT contacts, 7,500-ohm coil
K-4	Relay, midget, SPDT contacts, 24-volt, 150-ohm coil
S-1,2	Switch, toggle, SPST, 3 amp., 115-volt
S-3	Switch, micro, leaf actuated
S-4,6	Switch, PBNO
S-5	Switch, toggle, SPDT, 3 amp., 115-volt
T-1	Transformer, special, see schematic
P-1,2	Panel lamp, NE-51
F-1	Fuse, 2-amp., 250-volt
Rectifier 1	Selenium rectifier, half-wave, 135-volt r.m.s. input, 100-ma
Rectifier 2	Selenium rectifier, full-wave bridge, 28-volt r.m.s. input, 1½-amp
Motor	Synchronous clock motor, 1-r.p.m.
Bell	Small, 6–10 volt, electric bell or buzzer
Meter-relay (K-5)	D'Arsonaval-type relay, 1 ma, full-scale with movable upper contact or 50–100 microamp. fulll scale, with fixed contact (to be used with shunt)

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Radionuclides in Fused Enamel Make Stable Radiation Sources

By CLIFTON BLINCOE*
Department of Dairy Husbandry
College of Agriculture
University of Missouri
Columbia, Missouri

A satisfactory source of radiation must be chemically and physically stable as well as provide the desired energy spectrum. Fused enamel, essentially a glass, is among the most chemically stable surface coatings known. Many of the useful radionuclides are isotopes of elements either normally used in fused enamels or that may be incorporated into them. Thus enamels would appear to offer a very satisfactory method of mounting. Y^{91}, Sr^{90}, and Ce^{144} have been incorporated into glass beads by fusing the hydroxides or the carbonates of the nuclides with powdered glass (*1*).

Most methods of mounting radionuclides, apart from electroplating, do not render the nuclide an integral part of the surface coating. Examples of such methods are covering a deposited salt of the nuclide with plastic or containing it in a metal capsule. This introduces an absorber into the system. Among those radionuclides that can be electroplated, it is often necessary to cover the emitting surface so as to render it more resistant to abrasion.

Fused-Enamel Procedure

Radionuclides are mounted as components of a fused enamel in a manner similar to that used for applying decorative enamels to small jewelry (*2*).

The metal was first cleaned and rinsed in distilled water. A thick layer of crushed enamel was then applied. A small amount of alkali was placed on the enamel to neutralize the acidity of the radionuclide, and the desired amount of an acid solution of the radionuclide was placed on the crushed enamel with sufficient water to thoroughly wet the powder. The mixture was dried by mild heat.

After drying, the mixture was fused either in a gas flame or a muffle furnace. There was some, but not serious, contamination of the furnace. After the enamel was fused and the surface became glossy, it was cooled gradually. If enamel is fused in a gas flame, the flame must not touch the melt surface.

The sources were cleaned in appropriate decontaminating agents to remove any radioactivity not incorporated into the enamel. In the case of Sr^{90}-Y^{90} it was necessary to fuse a thin layer of nonradioactive enamel over the finished source to prevent leaching of activity.

This technique has been used to make sources of Pm^{147}, Tl^{204}, Sr^{90}-Y^{90}, and Cr^{51} on stainless steel, copper, and glass ranging from 0.8 mm to 25 mm in their major dimension. Thicknesses were 0.1–1 mm, but these do not represent limits. The activities have been of the order of 0.1 mc, but there is no obvious reason to preclude the use of this technique for stronger sources.

Chemical Stability

Tests of the chemical stability of the sources were made by the standard scrub, soak, and wipe tests (*3*).

The scrub test consisted of immersing the source in a decontaminating solution and scrubbing vigorously with a stiff, motor-driven nylon brush. The radioactivity of the solution was then determined.

The soak test consisted of immersing the source for 8 hr in a decontaminating solution at 50° C and determining the radioactivity of the solution.

The wipe test consisted of wiping the source with an absorbant material wet with a decontaminating solution and determining the radioactivity on the swab.

In all tests the decontaminating solutions were 10% sodium carbonate, 10% nitric acid, and 10% citric acid. These were chosen to ascertain the effect of alkaline, acid, and chelating reagents.

In all cases the wipe tests were negative—no measurable radioactivity was found on the swab. Scrub tests and soak tests removed less than

* PRESENT ADDRESS: Department of Agricultural Chemistry, University of Nevada, Reno, Nevada.

5×10^{-4} μc. This is approximately one-hundredth the currently permissable amount for sealed sources (*3*). The sources were least stable to nitric acid.

Radiation Characteristics

The ranges of the beta particles emitted by the weakest beta-emitter prepared (Pm^{147}) were compared with those of a weightless film of the isotope placed in a similar container. The ranges, as well as the aluminum absorption curves, were identical within the precision of the measurement ($\pm$1–5%). These data indicate that the radionuclides are very close to the surface of the enamel.

Although self-absorption is present, especially with low-energy emitters, the maximum energy of the emitter is readily available from these sources.

* * *

This article is a contribution from the Missouri Agricultural Experiment Station. The work was supported in part by the U. S. Atomic Energy Commission.

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Scintillating Gels

By B. LIONEL FUNT
Chemistry Department
University of Manitoba
Winnipeg, Canada

The use of single crystals and liquid and plastic organic solutions for detecting nuclear radiation by the methods of scintillation counting is well recognized. In this work a new type of scintillator, the scintillating gel,* is described.

This type of system appears well suited for internal counting applications, and promises to provide a new versatility to counting methods involving the suspension of tagged material or the incorporation of desired nuclear species. Counting systems utilizing scintillating gels embody low self-absorption for detecting alpha or beta radiation and excellent geometry. The viscosity of scintillating gels can be varied over wide limits and the relative luminescent efficiencies of such systems are high.

For alpha and beta emitters, the problems of sample counting with high efficiency and good geometry are often serious. The instances in which the tagged substance may be dissolved directly in a liquid scintillator without appreciable quenching are rare, and for inorganic salts the problems of sample incorporation are particularly difficult. The suspension of small particles has been suggested by Hayes (*1*, *2*), but this is not readily accomplished in liquids of low viscosity. Using a scintillating gel, radioactive material may be incorporated without appreciable settling, and can be effectively counted utilizing excellent geometry.

* Available commercially from Nuclear Enterprises Ltd., Winnipeg, Canada.

Preparation

Scintillating gels were prepared as follows.

To a liquid-scintillator solution containing *p*-diphenylbenzene and 1,4-bis-[2-(5-phenyloxazolyl)-benzene] (POPOP) in xylene, or a solution of phenylbiphenylyl oxadiazole (PBD) in xylene or toluene, 5% by weight of aluminum stearate was added with vigorous stirring.

The resultant colloidal solution was heated slowly to approximately 70° C at which temperature gelation occurred, and the slight turbidity of the original solution disappeared. Adequate care was taken in heating to avoid forming bubbles. The gel was then allowed to cool and its pulse height was measured.

Properties

With a Cs^{137} source, a pulse height of 60% of that of the original scintillator solution was obtained. Tests showed that deoxygenated scintillators yielded a higher relative light output (*3*), but the ratio of light outputs of gel to solution was unchanged.

The gels were completely transparent and colorless, but displayed the fluorescence of the original liquid scintillator solutions. Their viscosity could be varied over a wide range. At the highest concentrations (7–10%) the gels retained their shape even when inverted. At intermediate concentrations slow fluid flow could be obtained, while at low concentrations (under 1%) they possessed considerable mobility;

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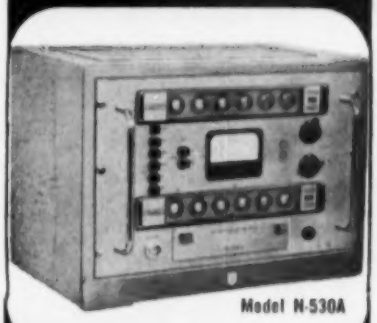

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the most useful range of aluminum soap concentrations appears to be between 2 and 7% by weight. The thixotropic behavior of aluminum soap systems is well known (*4*), and is exhibited in scintillating gels.

Internal sample counting was accomplished by injecting radioactive solution or a suspension of fine particles of active material into the body of the gel. Either a hypodermic needle or a fine glass rod proved suitable for introducing the sample into the gel. Care was taken that the individual particles or drops were sufficiently small to minimize self-absorption. An alternative procedure involved the incorporation of the active material into the solution just prior to gelation, and resulted in a reasonably uniform distribution of the sample throughout the gel.

The ratio of counting efficiencies of suspended versus dissolved C^{14} in liquid scintillation solutions has been found to be very high (*1*), and would be expected to be equally favorable in scintillating gels.

Gelation by the addition of various peptizing agents in the absence of heating also appears feasible. For example, gels of several aluminum soaps of various chain lengths were effectively peptized by the addition of phenol at concentrations under 1% by weight.

The methods outlined appear suitable for adoption for various tracer applications, such as for C^{14}, S^{35}, tritium, and alpha counting. They also offer possibilities for the incorporation of desired nuclei into heterogeneous systems, where problems of solubility or quenching action might otherwise limit their use.

* * *

The author is indebted to Nuclear Enterprises Ltd., Winnipeg, for the supply of samples, technical assistance, and co-operation in this work.

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Diode-Phototube Monitor Uses Liquid Scintillator

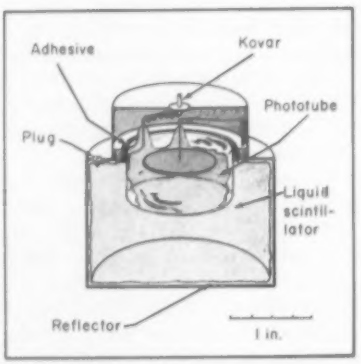
By W. R. LAMB
U. S. Naval Radiological Defense Laboratory, San Francisco, California

Portable radiacs have employed photomultipliers combined with crystalline phosphors. These detectors are costly, require high voltages, and are subject to environmental stresses. To obviate these difficulties, the present detector was developed, using a diode phototube and liquid scintillator.

The form-factor, though flexible, was fixed in one instance as shown in the illustration. The phototube is a vacuum diode (*1*). Recent models of this 29-mm-diameter tube have a mean photosensitivity of 97 μamp/lumen at a color temperature of 2,800° K.

The cathode lead is soldered to an opaque Kovar insulator in the cap. The anode is case grounded. The phototube is bonded to the case with EPON VI* adhesive. EPON VI provides a hermetic seal of about 1,500-psi shear strength. The glass-to-metal bond has proven inert to the toluene solvent after a one-year immersion.

The case interior is coated with a reflecting paint, which is composed of ZnS:Ag powder† suspended in sodium



LIQUID-SCINTILLATOR detector might be feasible for neutron detection

* Sample kindly supplied by Shell Chemical Corp.

† 33-Z-20A from Radio Corporation of America, or #1101 Type D from E. I. DuPont de Nemours & Co.

silicate. The paint is thus an excellent light reflector, inert to toluene, and moderates the energy dependence of the liquid scintillators. The liquid is introduced by syringe; then the entry hole is hermetically sealed by a set screw.

Typically, the liquid scintillator is 75 ml of purified toluene (*2*) with solutes of 5.50 gm/l PBD [2-phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole] and the wave-length shifter 0.133 gm/l POPOP [1,4-di-(5-phenyl-2-oxazolyl)-benzene] (*3*). After the liquid is syringed into the case, purified nitrogen or argon (*4*) is bubbled through the liquid for ten minutes to displace the dissolved oxygen.

In a radium-gamma radiation field of 1.0 r/hr, the detector produced 1.1×10^{-10} amp with 6 volts on the phototube. Of this current, 14.5% was contributed by the ZnS:Ag paint. The signal-to-noise ratio was greater than 47 db.

The dependence of current output on gamma-radiation energy is controlled by altering the thickness and material of the case, the proportion of ZnS:Ag in the reflecting paint, and the type and concentration of solutes in the liquid scintillator. Energy response of ZnS:Ag in the region of 100 kev increases with decreasing energy; the reverse is true for the above or similar liquid scintillators. Energy independence from about 60 kev to at least 1.3 Mev can thus be attained.

Temperature dependence of one model was $-0.44\%/°C$ change in output current. No mechanical rupture of detector components occurred from -20 to 50° C in the hermetically sealed units.

Sufficient space in the hermetically sealed cap of some detectors was allowed for inclusion of electronic components, such as cathode followers. A 1-mil stainless-steel window in the base of some models allowed beta-radiation detection. The $S(n,p)P^{32}$ process in ZnS:Ag and proton recoils in the hydrogenous liquid scintillator provide neutron detection feasibility.

* * *

This work was done with the encouragement of N. A. Marshall and A. H. Redmond and with the technical assistance of J. Valdivia.

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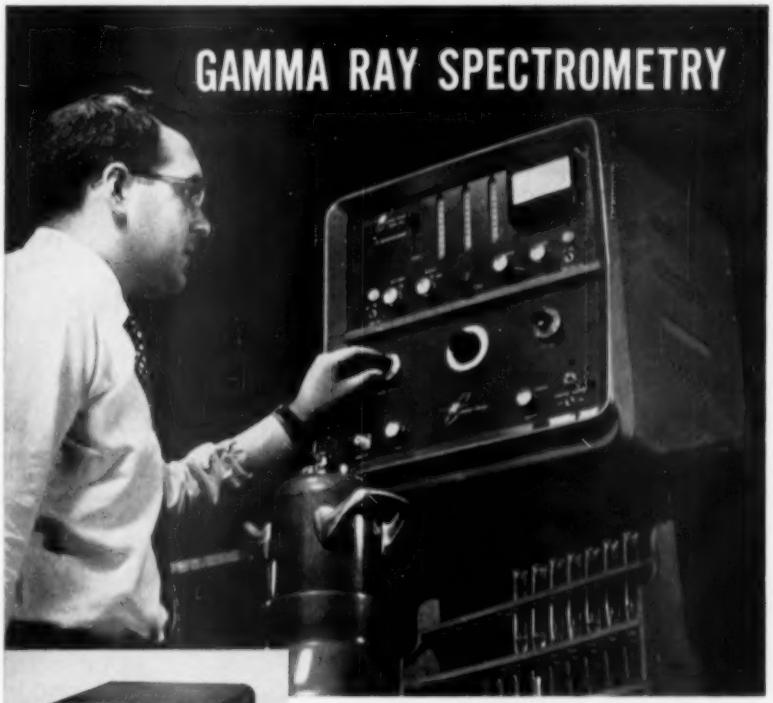

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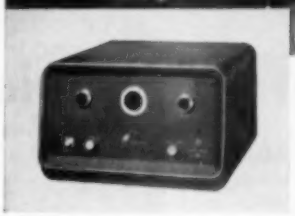

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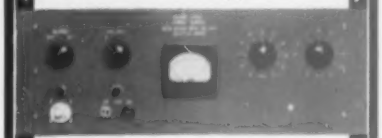

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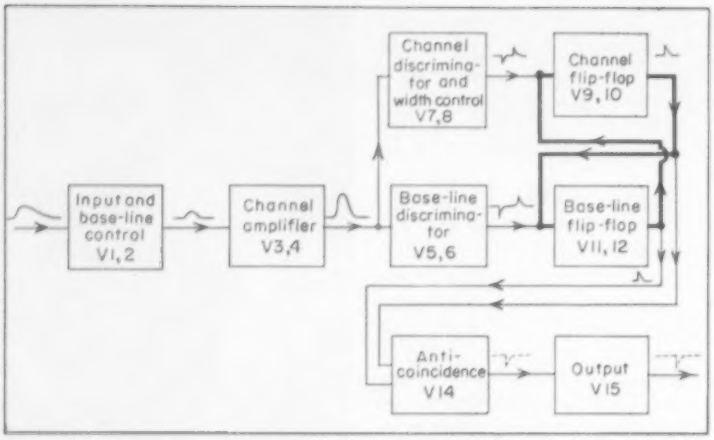

FIG. 1. Block diagram of single-channel pulse-height analyzer. Input circuit selects minimum pulse amplitude to be passed to following circuits. Channel amplifier amplifies selected portions ~10×. Amplified pulses are then fed into base-line and channel-width discriminators. Base-line discriminator produces negative pulse corresponding to leading edge of pulse at its input and positive pulse corresponding to trailing edge. Channel-width discriminator accepts pulses appearing at its input that are greater than a selected level and produces negative and positive output pulse corresponding, respectively, to upward and downward crossing of selected level by input pulse. Base-line and channel flip-flops, through a feedback arrangement, serve to make positive pulses time coincident to suit anticoincidence circuit

Fast Differential Analyzer

By HAROLD A. LAMONDS
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The single-channel pulse-height analyzer presented here avoids delaying and stretching techniques yet has 0.4-μsec resolving time. Time coincidence of the pulses from the two discriminators is obtained by a feedback technique. Figures 1 and 2 show the circuit elements and the pulse sequences.

Figure 3 is a schematic diagram of the circuit; the accompanying box describes its operation. Thus operation of the circuit is described in the first three figures and the remainder of the text will be devoted to design problems and calibration.

Two of these analyzers have been built. One has now been in use for over a year requiring no maintenance other than normal tube replacements. They have proved to be reliable and stable.

The Problem

One of the factors that complicate the design of a differential discriminator type of pulse-height analyzer and often leads to long resolving times is the finite (and sometimes substantial) rise and fall times of the pulses that are to be measured. Figure 2 shows that the

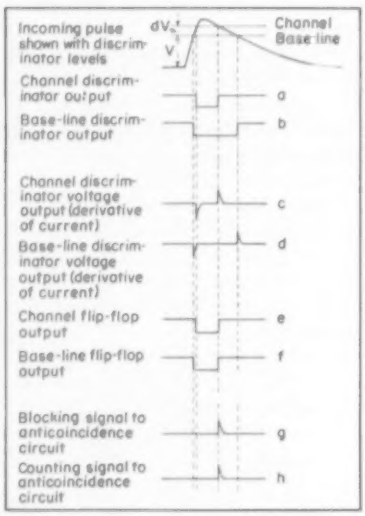

FIG. 2. Time relationship between pulses at various points in the analyzer. Design provides means for selecting portion of counting pulse that occurs at instant blocking pulse is ending, and feeding these two time-coincident signals into anticoincidence circuit. Rectangular output pulses *a* and *b* from blocking and counting discriminators are shaped by shorted 0.05-μsec delay lines to provide first a negative, then a positive, pulse *c* and *d*. These voltage pulses are used to trigger high speed flip-flop circuits from an initial state to the other stable state and then back to its initial state producing outputs *e* and *f*, which, when differentiated (*g* and *h*) give time-coincident inputs for the anticoincident circuit

lower (or counting) discriminator is triggered before and remains triggered after the upper (or blocking) discriminator. If the pulses from the two discriminators were fed into a fast anticoincidence circuit, there would be a pulse fed out to the scaler even when the blocking discriminator was tripped because the leading edge of the counting-discriminator pulse would pass through the anticoincidence circuit before the blocking-discriminator pulse came into existence. It is, therefore, not feasible to allow the anticoincidence circuit to accept the leading edge of counting-discriminator pulses unless a delay circuit is incorporated.

An alternative plan would be to differentiate the counting-discriminator pulse, so as to produce, say, first a negative, then a positive, pulse. The anticoincidence circuit could then be designed to accept only a positive signal from the counting discriminator, with the blocking signal being provided by stretching the pulse from the blocking discriminator. For the case where the measuring channel is near the base of a given pulse, one sees that the counting pulse can exist considerably longer than the blocking pulse. This requires stretching the blocking pulse considerably to insure operation of the anticoincidence circuit when the channel is measuring low-amplitude pulses in the presence of large pulses. It is generally not feasible to make the amount of stretching variable, and therefore, this extended blocking pulse adds materially to the resolving time.

Bandwidth and Pulse Shape

One can gain an appreciation for the band-width requirements in the channel amplifier from the following example: Assume the input is provided by an amplifier having a response governed by equal high- and low-frequency time constants so as to achieve a maximum signal-to-noise ratio (*2*). The input wave-form can than be represented by $E(t) = ete^{-t}$. With this shape, a 100-volt, 0.5-μsec pulse will exceed the 99-volt level for only 0.028 μsec. To amplify faithfully such a short pulse would require a bandwidth of about 25 Mc, if one assumes this peak to be essentially triangular and uses the relationship (Rise time) $\times$ (Band width) = 0.35 (*3*).

To overcome this requirement, many experimenters prefer to use delay-line shaping of the input pulse; this has the advantage of providing a relatively flat-topped pulse, which requires less

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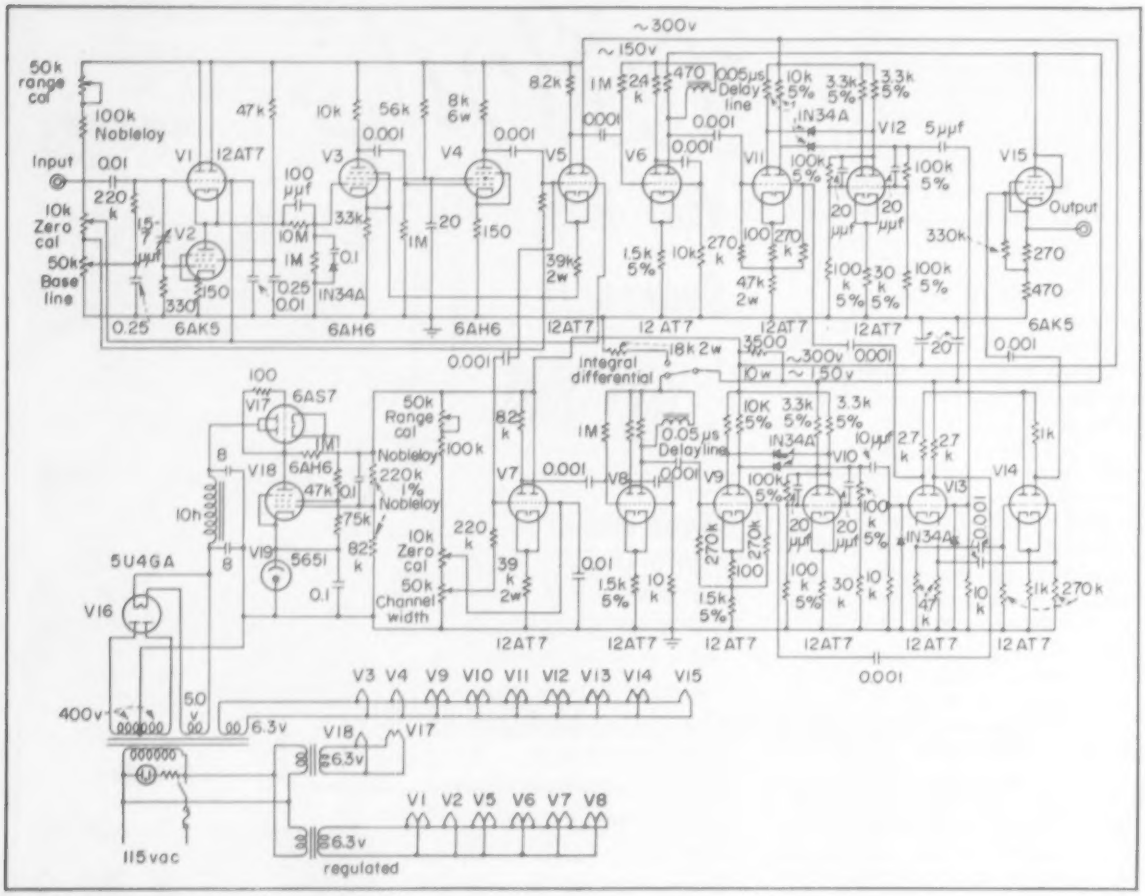

FIG. 3. Schematic for single-channel pulse-height analyzer

Channel amplifier. *V1* acts as biased-input cathode follower; three-stage feedback amplifier, *V1b*, *V3*, and *V4*, in cascade provides gain. First half of *V1* is biased off by a 10-turn helical potentiometer that selects base line (minimum pulse amplitude to be passed). *V2* provides a high dynamic cathode load for *V1* and neutralizes grid-cathode capacitance of *V1* via variable coupling capacitor to grid of *V2* and resulting paraphase signal appearing at cathode of *V1*. Without this, large pulses having fast rise times would leak into channel amplifier and result in counts even when substantially lower than set bias level.

Stability of input bias level is improved by use of regulated power supply and stable resistors. Filament supply for *V1* and *V2* is also regulated to reduce contact-potential drift and changes in emission due to cathode temperature changes. Negative feedback reduces gain drift in the channel amplifier.

bandwidth in the channel amplifier. A compromise must be made in arriving at the bandwidth to be designed into the channel amplifier. This would indicate that, to take full advantage of the short resolving time of this analyzer, one would have to use delay line shaping on the pulses to be fed into it. The nature of the design, however, allows pulses of practically any shape to be fed into it, but if a high accuracy is desired, care must be taken to insure that the pulses to be counted remain in the counting channel for a time consistent with the bandwidth of the channel amplifier.

The present analyzer has an amplifier rise time of 0.1 μsec and the discriminators will trigger and recover in at least 0.3 μsec.

Calibration

Calibration was performed using a precision pulser, a Tektronix 514D oscilloscope, a differentiating network having an *RC* time constant of 1 μsec and a linear amplifier. The output pulse from the pulser is shaped by the differentiating network and fed into the linear amplifier. The gain of the amplifier is then adjusted to exactly 1,000 as measured by the oscilloscope so an output of 100 volts is obtained when the pulser is set to 100 millivolts. The output of the amplifier is then fed into the pulse-height analyzer.

Base line. With the analyzer base-line control set to 100 volts and the channel-width control set to maximum width, the range calibrate control for the base line is adjusted until the analyzer produces an output pulse, but will fail to do so if the input is reduced 0.1 volts. The input is now reduced to 5 volts and the analyzer base-line control set to 5 volts. The zero calibration control for the base line is then adjusted until the analyzer is producing an output pulse but will fail to do so if the input is reduced by 0.1 volts. The procedure is then repeated until no further adjustment is necessary. The base-line setting to produce an output pulse from the analyzer is then meas-

Discriminators. Channel and base-line discriminators follow channel amplifier. Base-line discriminator operates at fixed bias of ~1 volt. Referred back to analyzer input, signal 0.1 volt above set input bias level will trigger base-line discriminator. Channel discriminator operates on variable bias that can be set to accept 0–100-volt pulses from the channel amplifier. Referred back to analyzer input, this gives an adjustable channel width of 0–10 volts. Thus, base line can be set from 0.1 to 100 volts by adjusting bias by base-line control on *V1*, and channel width can be adjusted from 0 to 10 volts by channel-width control on *V7*.

Base-line discriminator is *V6*, with *V5* acting as a biased phase inverter. Channel-width discriminator is *V8*. Phase inverter, *V7*, also selects pulse level at which *V8* trips. High-speed discriminators do not trigger reliably at widely varying discrimination levels so biased amplifier, *V7*, is used to allow discriminator, *V8*, to operate at fixed level.

Flip-flops. Counting flip-flop circuit is *V12*, diode coupled to preceding buffer, *V11*. This buffer serves several purposes. First, it limits plate excursion of flip-flop by diode coupling to improve switching speed. It also provides amplification for small triggering signals, and finally, provides a mixing circuit for injection of fed-back blocking signal. Blocking flip-flop circuit consists of *V10*, diode-coupled to preceding buffer, *V9*, and in all other ways is identical to counting flip-flop.

Feedback. Outputs from flip-flop stages (e and f, Fig. 2) are differentiated by *RC* network and fed into another amplifier, *V13*. Trailing edge of blocking pulse is selected by diode clipper at grid of *V13a*. This pulse is then inverted, amplified and fed back to grid of *V11b*, buffer tube for counting flip-flop. This reset pulse, arriving before counting pulse ends, resets counting flip-flop, thus assuring time coincidence of trailing edges of output pulses from the two flip-flops. Trailing edge of counting discriminator pulse arrives later, but has no effect, since counting flip-flop has already been restored to its initial condition.

One further consideration must be taken into account in the feedback arrangement. The discriminators will produce an output pulse that lasts about as long as the incoming pulse remains greater than the discrimination level. This is true down to some minimum duration, but if the incoming pulse becomes shorter than the minimum, the discriminator pulse remains essentially fixed in duration. Under certain circumstances, it is possible that the blocking pulse may become longer than the counting pulse, thus making it impossible for the trailing edge of the blocking pulse to achieve time coincidence with the trailing edge of the counting pulse. In such a case, the counting pulse would pass into the anticoincidence circuit and be counted before the blocking pulse came along.

It is seen that in many cases the time spent by the incoming pulse above the triggering levels of the two discriminators may differ by less than 0.1 μsec. Thus, if both discriminators are triggered by a pulse shorter in duration than the minimum discriminator-output pulse duration, one could not tolerate much extension of the minimum pulse duration of the blocking discriminator without having its trailing edge exist later than that of the counting discriminator. To forestall this possibility, provisions are made for feeding back the trailing edge of the counting pulse to the blocking flip-flop, so that it will be restored to its initial state at the end of the counting pulse, even if the blocking discriminator pulse exists longer. We now see that, regardless of the duration and time relationships of the pulses from the two discriminators, the trailing edges of the pulses from the two flip-flop circuits will be time coincident, and therefore they are suitable for feeding into an anticoincidence circuit.

Anticoincidence. Positive voltage pulses (g and h, Fig. 2) corresponding to differentiated trailing edges of blocking and counting flip-flop pulses are taken from cathodes of *V13a* and *V13b* and fed into anticoincidence circuit, *V14a* and *V14b*. At this point blocking pulse is slightly longer than counting pulse, due to *RC* differentiating network having 0.1-μsec time constant for shaping blocking pulse as opposed to 0.05-μsec time constant for counting pulse. This is to insure that no part of counting pulse exists longer than blocking pulse.

Counting pulse is fed to grid of *V14b* and blocking pulse to grid of *V14a*. Two halves of *V14* are cathode-coupled and output taken off plate of *V14b*. Thus signal fed into grid of *V14b* suffers phase reversal, while signal fed into grid of *V14a* does not. If identical signals of same polarity are fed simultaneously to the two grids, result would be no output if we neglect or correct for capacity effects. If, on the other hand, a positive signal is fed into grid of *V14b* and no signal is present at grid of *V14a*, there would be a negative output signal. The first case corresponds to pulse of amplitude greater than base line plus channel width. Second case corresponds to pulse falling within channel.

Output. Negative anticoincidence output pulse is fed to cathode follower to drive coaxial cable to scaler. As was mentioned earlier, blocking pulse into anticoincidence circuit is slightly longer than counting pulse. Hence we have a small positive signal when blocking occurs. This would not, in general, be disadvantageous, since most scalers and ratemeters that might be used to follow this analyzer are sensitive only to negative pulses and would not be triggered by these superfluous positive pulses. Should these positive output pulses become undesirable, it would be easy to remove them by diode clipping at grid of *V15*.

ured as a function of input voltage. These data are shown in Fig. 4. It is seen that the base-line control is linear to within 0.1 volts, which is 0.1% normal linearity in a 100-volt range.

Channel width. The channel width is calibrated with the same test arrangement as the base line. The base-line control is set to some arbitrary voltage below 90, say 50 volts. The pulser is then set to produce an input voltage 10 volts higher than the base line, in this case, 60 volts. With the channel-width control set at 10 volts, the channel-width range calibrate control is adjusted until no output pulse appears unless the input pulse height is reduced by 0.1 volts. Now the input is reduced

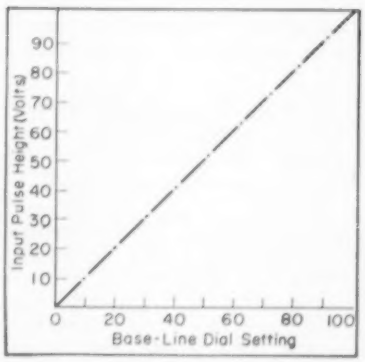

FIG. 4. Base-line calibration is linear to 0.1 volts (0.1% normal linearity in 100-volt range)

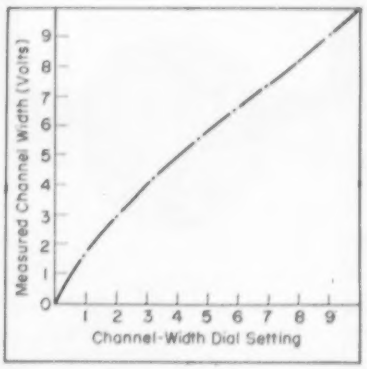

FIG. 5. Channel-width calibration. Width is determined from input pulse height above base line required to cancel output

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to 50.5 volts and the channel-width control to 0.5 volts. The channel-width zero calibrate control is then adjusted to produce no output unless the channel-width control is opened to 0.6 volts. The procedure is then repeated until no further adjustment is necessary. The channel-width control setting is then measured as a function of the input pulse height above the base line required to just produce cancelling of the output pulse. These data are shown in Fig. 5.

Resolving time. Resolving time was measured with a Berkeley 903 double-pulse generator and a Tektronix model 514D oscilloscope. The pulser output is set for minimum-duration pulses and maximum separation between the double pulses. The output is then fed into the analyzer and the output of the analyzer is connected to the oscilloscope. Now the base-line and channel-width controls of the analyzer are adjusted until the peaks of the input pulses are at the approximate center of the channel. The separation between input pulses is then reduced while observing the output pulses from the analyzer to determine the separation at which the second of the two pulses is no longer resolved. This separation is then the resolving time for pulse pairs. Frequent checks must be made on the input pulses to see that they do not change either in absolute or relative amplitude as the separation between them is reduced. These measurements show the resolving time as <0.4 μsec.

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Continuous Alpha Air Monitor

By DAVID R. SAWLE *
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Livermore Site, Livermore, California

The concentration of natural alpha-emitting isotopes in the air varies widely and is many times greater than the maximum permissible concentration of some of the longer-lived heavy-element isotopes. It is thus difficult to distinguish dangerous isotopes from natural background.

The system of collecting a dust sample on a filter paper and allowing the shorter-lived natural activity to decay before counting gives an excellent measure of the long-lived activity in the air at the time the sample was taken. However, in handling large quantities of the more dangerous isotopes, it is possible to have a dangerous concentration in the air and not know it until later (possibly 48 hr). Also, it may be difficult to detect the source of activity if the reading is delayed.

Of several approaches to a faster meter response, the type employing a moving filter paper is the most common (*1*). In some instances an

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Comparison of Monitor and Ionization Counter

Sample	Continuous monitor: Total counts (gross bkgd net)			Continuous monitor: Long-lived counts (gross bkgd net)			Total counts	Time after sampling (min)
Pu 1				1,950	600	1,350		
U 1				2,400	1,400	1,000		
2				3,000	1,950	1,050		
3				1,500	500	1,000		
4				1,000	100	900		
5				1,700	500	1,200		
6	5,500	3,000	2,500	1,600	600	1,000	3,620	10
7	7,000	3,000	4,000	2,900	1,000	1,900	4,086	25

* Corrected to 25% geometry and for decay. † Corrected to 25% geometry.

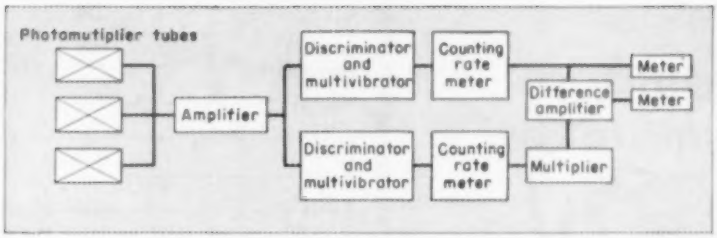


FIG. 1. Continuous alpha air monitor

identical monitoring head is placed outside the radioactive area and the reading subtracted from the reading obtained in the active area.

The approach used in this instrument (see Fig. 1) is to continuously monitor a stationary filter, allowing the activity to reach equilibrium, compensating for the natural activity by subtracting its pulse height from that of the total activity. The natural activity in the air is from radon and thoron (gaseous decay products of uranium and thorium present in the earth) and their decay products. The natural activity on the filter paper is mainly from the decay products of radon. The thoron daughters will not influence the results unless the filter paper is used for over 8 hr in a thoron-rich atmosphere.

Analysis of Natural Activity

The radon in the air will be essentially at equilibrium with its daughter products so that for every disintegration of a radon atom, an atom of Ra A in the air will disintegrate, i.e.

$$\frac{dN_{Rn}}{dt} = \frac{dN_A}{dt} = \frac{dN_B}{dt} = \lambda_A N_A = \lambda_B N_B, \text{ etc.}$$

where N_A, N_B, N_C, $N_{C'}$ are the number of atoms of radium A, B, C, C′, respectively.

λ_A, λ_B, λ_C, $\lambda_{C'}$ are the decay constants of radium A, B, C, C′, respectively, and t is the sampling time.

A short time after sampling is started, the amount of natural activity being collected will equal the amount decaying. At this equilibrium condition, the number of atoms of Ra A, B, C, and C′ on the filter paper will remain constant. Therefore

$$dN_A/dt = FC/\lambda_A - \lambda_A N_A = 0 \qquad (1)$$

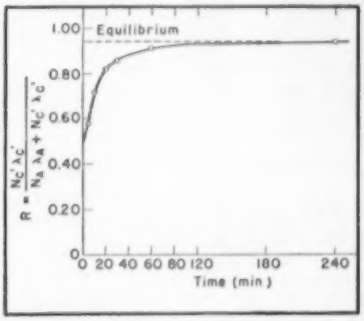


FIG. 2. Ratio (R) of 7.68-Mev RaC′ alpha particles to total number of alpha particles on filter paper filtering air containing radon. Data taken from table

Paper counter			
*Total corrected cpm**	*Long-lived cpm*	*Corr. long-lived cpm†*	*Diff. from monitor*
	2,060	1,030	320
	3,240	1,620	620
	3,720	1,860	810
	1,980	990	10
	3,370	1,690	790
	3,410	1,700	500
2,250	2,180	1,090	90
2,730	2,370	1,180	720

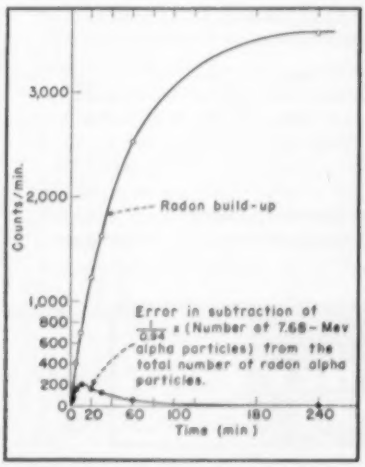
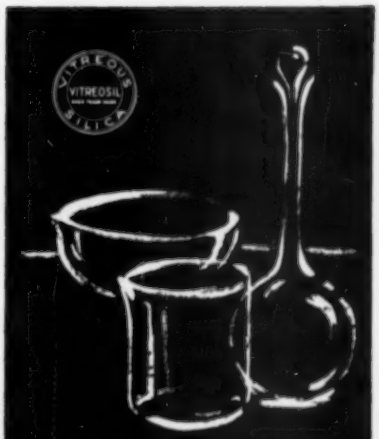


FIG. 3. Radon buildup on filter paper. Radon concentration 2×10^{-10} μc/cm³, sampling rate 16 ft³/min, 25% geometry



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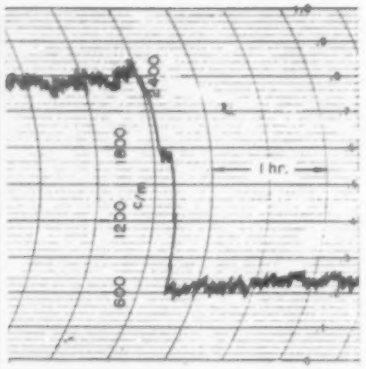

FIG. 4. Esterline-Angus chart recording shows rapid response of monitor

$$\frac{dN_B}{dt} = \frac{FC}{\lambda_B} + \lambda_A N_A - \lambda_B N_B = 0 \quad (2)$$

$$\frac{dN_C}{dt} = \frac{FC}{\lambda_C} + \lambda_B N_B - \lambda_C N_C = 0 \quad (3)$$

$$\frac{dN_{C'}}{dt} = \frac{FC}{\lambda_{C'}} + \lambda_C N_C - \lambda_{C'} N_{C'} = 0 \quad (4)$$

F is the flow rate of air through the filter. C is the concentration of radon in the air expressed as dpm per unit volume. Adding Eqs. 1–4 gives

$$N_{C'}\lambda_{C'} = FC[1/\lambda_A + 1/\lambda_B + 1/\lambda_C + 1/\lambda_{C'}]$$

Since Ra A and Ra C′ are the only two alpha emitters in the chain the ratio of Ra C′ to the sum of Ra C′ and Ra A would be of interest.

$$\frac{N_{C'}\lambda_{C'}}{[N_A\lambda_A + N_{C'}\lambda_{C'}]} = \frac{FC\left[\frac{1}{\lambda_A} + \frac{1}{\lambda_B} + \frac{1}{\lambda_C} + \frac{1}{\lambda_{C'}}\right]}{FC/\lambda_A + FC\left[\frac{1}{\lambda_A} + \frac{1}{\lambda_B} + \frac{1}{\lambda_C} + \frac{1}{\lambda_{C'}}\right]} = 0.94$$

This means that 94% of the alpha particles emitted from the activity on a filter paper are the 7.68-Mev alpha particles from Ra C′. This α energy is at least 30% greater than that of the alpha particles from the dangerous isotopes we wish to detect. Therefore it should be a simple matter to discriminate between them and subtract the high-energy counts from the total counts to give the number of counts due to dangerous isotopes.

Nonequilibrium Errors

Before equilibrium is reached, differential Eqs. 1–4 are no longer equal to zero but can be solved simultaneously to give

$$N_{C'} = FC[2.76 \times 10^{-4} - 4.11 \times 10^{-7}e^{-\lambda_A t} - 6.47 \times 10^{-4}e^{-\lambda_B t} + 3.71 \times 10^{-4}e^{-\lambda_C t}]$$

also

$$N_A = [FC/\lambda_A{}^2]\,[1 - e^{-\lambda_A t}]$$

Using these two equations the following values can be obtained (plotted in Figs. 2 and 3): R = ratio of 7.68-Mev alpha particles to the total number of alpha particles present on the filter paper; P = total radon activity on a filter paper; and E = error in the reading for the first few minutes of operation due to nonequilibrium conditions (difference between the total number of alpha particles and 1/0.94 times the number of 7.68-Mev alpha particles).

Figures 2 and 3 show that equilibrium is reached in about an hour and that for a radon concentration of 2×10^{-10} $\mu c/cm^3$ the error in the reading due to nonequilibrium conditions is never very large.

Instrument Design

The instrument consists of a Roots-Connersville blower drawing 16 ft^3/min of air through three 4¾-in.-diameter molecular filter papers (*2*). A lens-reflector system coated with silver-activated zinc sulphide and three photomultiplier tubes are mounted over the filter papers (Fig. 1).

The phototube signal goes through an amplifier to two discriminators. One discriminator passes pulses that are over 6.1 Mev. The other passes all pulses over noise level. The pulses passing through the circuit are then shaped in a multivibrator and integrated in a counting-rate meter circuit. The pulses over 6.1 Mev are multiplied electronically by a constant to correct for those high-energy pulses that show up as low-energy pulses due to energy losses (*3*).

The voltage obtained by integrating the pulses over 6.1 Mev multiplied by this constant is subtracted from the voltage obtained by integrating the total number of pulses. The remainder voltage is proportional to those alpha counts that are less than 6.1 Mev (the long-lived activity) and is indicated on a meter and an Esterline-Angus recorder. An alarm bell warns the operator when the long-lived activity is greater than a preset value. Another meter indicates the total number of counts.

Data Obtained

The table shows some typical values obtained. Bursts of plutonium and uranium aerosols were generated and allowed to collect on the filter paper. The monitor's response was almost

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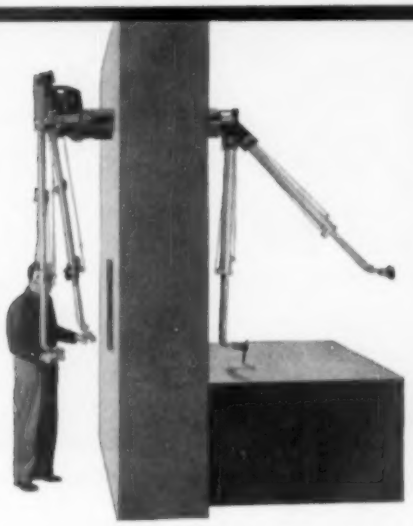

Model 8 is the newest in the line of CRL Master-Slave Manipulators. Central Research Laboratories has assumed the responsibility of designing and producing manipulators that perform with reliability and dexterity, and, as part of this program, the Model 8 was developed by Central Research under contract with Argonne National Laboratories. The Model 8 is a thru-wall design that is suitable for intermediate and high-level shielded enclosures. This general purpose manipulator enters the shielding barrier through an 8½ inch hole or slot.

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immediate, as indicated in Fig. 4. The filter papers from the continuous alpha air monitor were counted in the filter-paper counter after the radon and thoron daughters had decayed. The filter-paper counter is an alpha ionization counter (geometry is approximately 50%) connected to a scaler. Two of the sets of filter papers were counted shortly after removal to compare the total activity readings.

The table illustrates the fact that this meter will not give readings with a high degree of accuracy. However, it gives an approximate value that will warn the operator that contamination is present in the air. Some difficulty occurs with chamber contamination, but this situation should be improved with better chamber design.

Detectable Levels

With normal amounts of radon present in the air and a reasonably clean atmosphere 2,000 cpm can be easily detected. This 2,000 cpm is at a counting geometry of 25% and an air flow of 16 ft³/min. Thus after 8 hr of sampling it would require the following concentration to give an indication of 2,000 cpm on the meter

$$\frac{2{,}000 \text{ cpm}}{25\%} \times \frac{1}{8 \times 60 \times 16} = 1.04 \text{ dpm/ft}^3$$

or 36.5 dpm/meter³.

This means that an atmosphere containing approximately one-half the maximum permissible level of uranium, 66.6 dpm/cubic meter (4), would show up as 2,000 cpm on the alpha air monitor after 8 hr of sampling. Higher levels would show up in proportionately shorter times. Thus, the operator would have a positive indication on the instrument by the time he had received one-half his maximum daily dose.

Since the maximum permissible level of plutonium is ten times lower, the operator would not have a positive indication on the instrument until he had received five times his maximum permissible daily dose. However, there are several things that can be done to reduce the activity level that can be recognized as a positive indication that there is long-lived activity present in dangerous quantities.

Importance of clean room air. Large amounts of dust on the filter paper influence the readings since it alters the pulse heights. Filtering the

inlet air supply to the room also reduces the amount of radon and thoron and their daughters present in the air, which increases the instrument's sensitivity and accuracy. The larger the amount of radon and thoron present, the less accurate is the instrument since larger numbers are being subtracted by the instrument.

Instrument Limitations

By keeping the instrument in careful adjustment, it could be used in operations involving curium-242 and most other high-energy, alpha-emitting isotopes. However, it works best for alpha emitters of <5.5 Mev.

It is completely insensitive to beta and gamma radiation and slightly sensitive to high neutron fluxes.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission.

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Calibrated Bench Used for Gamma Standardizing

By D. E. HULL and G. H. KEIRNS
California Research Corporation
Richmond, California

In our radiochemistry laboratory, we have a convenient arrangement for quickly standardizing the gamma activity of tracer preparations.

The arrangement uses the inverse-square law to reduce a wide range of activities to a small range of counting rates on a G-M tube. Use of the square roots of integers to measure distances from the counter tube makes it easy to calculate activities.

The G-M tube is mounted in a fixed position at the end of a long bench. Standard positions are marked on the bench at the distances shown in Table 1 (also see the illustration).

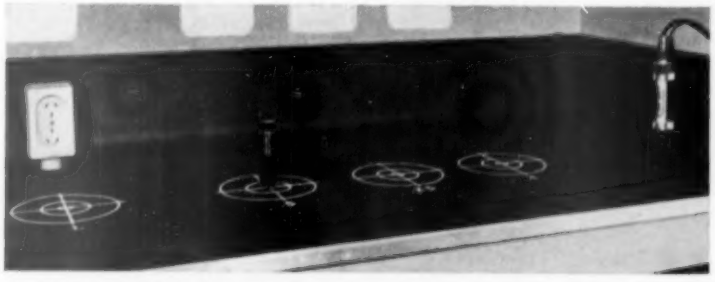
This convenient device is calibrated in this way: A radioactive specimen containing a known number of millicuries of a single isotope is placed in the 1-meter position. The counting rate of this specimen is measured and corrected in the usual way for coincidence loss and background. The calibration factor for this isotope is the ratio be-

TABLE 1—Co^{60} Calibration Factors

d(meters)	d^2	F(cps/mc)	Fd^2
0.316	0.1	481	48.1
0.500	0.25	203	50.8
0.707	0.5	106.2	53.1
1.000	1	55.0	55.0
1.414	2	28.4	56.8
1.732	3	19.01	57.0
2.236	5	11.57	57.8
3.162	10	5.72	57.2
4.472	20	2.95	59.0
5.477	30	1.910	57.3

TABLE 2—Calibration Factors at $\sqrt{0.5}$ Meter for Cobalt-60

Sample form	F(cps/mc)	*Deviation* (%)
Wire	111.8	
1-dram vial	108.0	−3.4
2-dram vial	106.2	−5.0
4-dram vial	104.8	−6.3
8-dram vial	104.8	−6.3
2-oz square bottle	104.9	−6.2
4-oz square bottle	102.2	−8.6
8-oz square bottle	100.6	−10.0



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tween counting rate and activity in units of counts/second/millicurie. This factor may then be used to standardize other samples of the same isotope counted in the same position. A sample that counts too fast or too slow at this position may be placed at another standard position to get a convenient rate. The counting rate is multiplied by the value attached to the position, then divided by the 1-meter factor. This gives a quick standardization accurate to a few per cent.

To illustrate: A 2-dram vial of cobalt-60 solution, known to contain 0.554 mc by comparison with a NBS standard, counts 30.41 cps in the 1-meter position. The calibration factor for cobalt-60 is thus $30.41/0.554 = 55.0$ cps/mc. Now, a sample of irradiated cobalt wire is found to count 166.4 cps at position 10, 3.162 meters away. Hence, it is $166.4 \times 10/55.0 = 30.3$ mc.

Gamma-ray scattering from the bench and walls of the room limits the accuracy of the method. Accuracy is improved by calibrating other positions with the standard. At points too close or too distant for counting the standard at convenient rates, a weaker or stronger preparation of the same isotope is substituted and its strength determined by comparison with the standard at a suitable position. Thus, by overlapping ranges with graduated secondary standards, the entire range of positions may be calibrated with reference to the primary standard. The factors found for cobalt-60 in the various positions along this bench are given in Table 1. These positions are satisfactory from 0.2 to 2,000 mc.

If a primary standard is not available, we calculate the counting rate at 1 meter from the disintegration scheme for the isotope. If the disintegration scheme or the gamma-ray spectrum is not known, we take the nominal strength of an isotope shipment from Oak Ridge and measure it in the 1-meter position to establish a laboratory standard for that isotope. Having fixed a value of cps/mc at 1 meter by one means or another, we then calibrate other positions as described.

For higher accuracy, it is necessary to consider the geometry of the radioactive source. Absorption in the container walls and self-absorption in radioactive solutions reduce the counting rate measurably. This is illustrated by the data in Table 2, all taken with the same cobalt-60 sample, first as a thin wire, then in solutions at successively greater dilutions.

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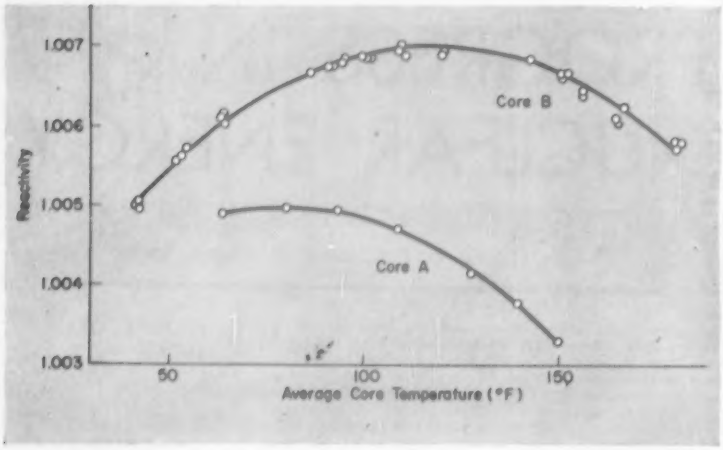


FIG. 1. Total core reactivity of two core loadings of ASTR as a function of temperature. Slope is temperature coefficient of reactivity; for Core B, this is positive at low temperature, reverses at about 120° F, and remains negative to at least 180° F with a value of about $-3.2 \times 10^{-5} \Delta k/°$ F. Core A has an inflection at about 80° F and a temperature coefficient of about $-3.9 \times 10^{-5} \Delta k/°$ F at high temperatures

Temperature Coefficient of Aircraft Shield Test Reactor

By J. C. NANCE
Convair Division
General Dynamics Corporation
Fort Worth, Texas

The temperature coefficient of reactivity of Convair's Aircraft Shield Test Reactor has been measured for two core loadings. The results are shown in Fig. 1. The loadings are shown in Figs. 2 and 3. To make the tests, we used preheated water to vary the uniform core temperature in small increments and then measured total core reactivity with calibrated control rods.

The ASTR is a 1-Mw Convair-designed-and-constructed test reactor intended for either ground operation or airborne operation in a modified B-36. The reactor has been operated in flight several times in support of the Air Force ANP program.

The reactor is moderated by water and uses MTR-type fuel elements with a loading of 150 gm of U^{235} per element. Elements are horizontal and supported at each end by aluminum adapters in fore-and-aft grid matrices. Two cylindrical cadmium-steel safety rods, 2¼ in. in dia, occupy central core voids. A dynamic rod, physically similar to the safety rods, is located on the core periphery.

Temperature Control

We changed bulk core temperature in small steps. It was automatically controlled by the ASTR ground moderator system that circulates preheated demineralized water through the core in a single-pass system. The water was heated by calrod units in a separate mixing tank. With this method we could hold the temperature at any level between room temperature and 180° F. With crushed ice we could reduce core temperature to a minimum of about 40° F.

Seven iron-constantan thermocouples indicated temperatures at various locations in the reflector. Reactor power was held at 2 watts to minimize interference from fission-product poisoning and local heating in the reactivity measurements.

Reactivity Measurements

At each stable temperature, the total core reactivity was determined by measuring the total reactivity value of inserted control rods by overlapping pile-period methods. This was necessary because the control rods exhibited temperature-dependent effectiveness. Measurements based only on rod position differences would have been in error due to this dependency.

Two interesting features of the results, shown in Fig. 1, are: (a) the existence of positive temperature coefficients for both core loadings, and (b) the difference between inflection points in the two cases. While no analytical treatment of this subject has been performed, it is apparent that the results are tied quite strongly to the existence of sizable fuel voids in the core.

* * *

This experiment was performed by members of the reactor operations group of Convair at Fort Worth as part of the low-power calibration of the Aircraft Shield Test Reactor.

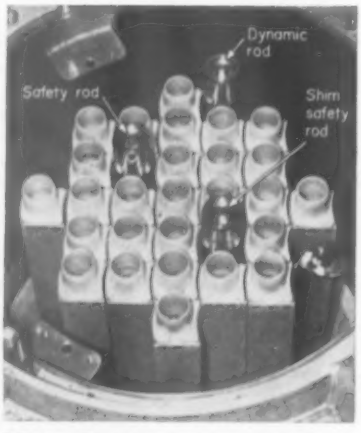


FIG. 2. Core A is a close-packed array of 27 fuel elements (4,050 gm of fuel) with two safety rods and a dynamic rod at the periphery

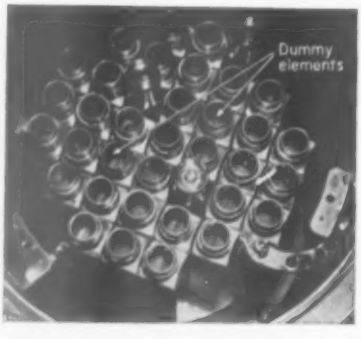
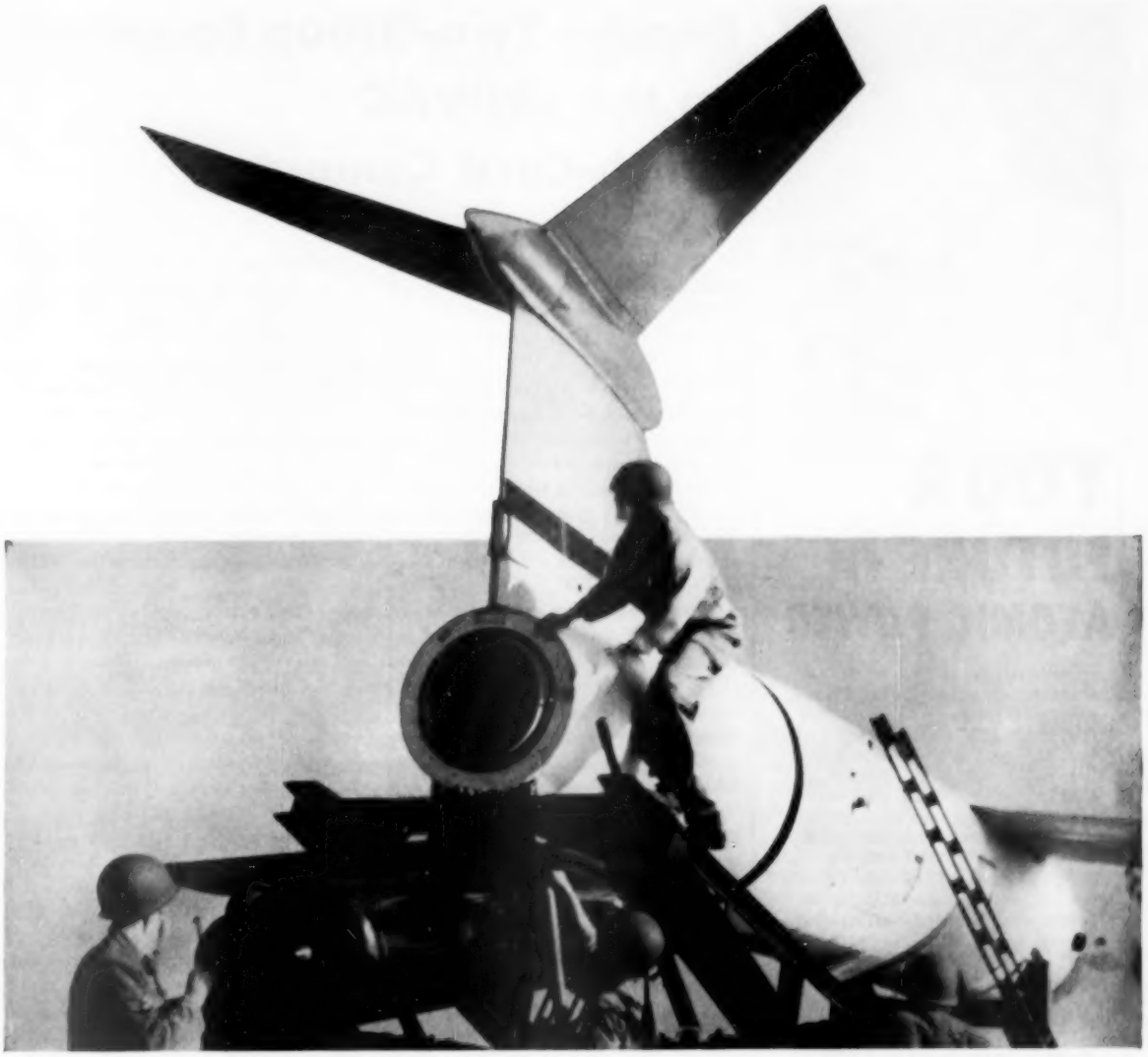


FIG. 3. Core B is a more open array of 32 fuel elements (4,800 gm fuel) with dummy elements near the center as corrosion-test specimens



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Reactor Two-Group Equations on the UNIVAC Punch-Card Computer

By J. R. LAMARSH and
S. S. RIDEOUT
Brookhaven National Laboratory
Upton, N. Y.

Many small organizations and universities would like to do reactor computations on electronic computers, but are prevented from doing so because the problems usually are considered too big for all but large-scale machinery. But the UNIVAC series-409 computers, about 500 of which are in business use in the U. S., can be utilized.

Reactor equations. Calculation of reactor critical sizes and masses requires, in principle, the determination of the neutron flux throughout the reactor. Since this is distributed in both energy and space, the general solution of the problem is very difficult. But, for thermal reactors the calculation can be simplified greatly by using the two-group method. In this procedure, the energy dependence of the flux is eliminated by lumping together into two groups all neutrons whose energy is greater than or less than some specified value. In this way, after suitable average parameters have been defined for each group, the flux is determined from two differential equations, one for each group. The solution of these equations then leads to a complicated transcendental eigenvalue equation from which the critical size or mass is determined.

Computers needed in reactor design. Since in reactor design studies many computations of critical size or mass usually are required, repeated numerical solution of this eigenvalue equation is very tedious. Thus, it is convenient to perform as much as possible of the computations on automatic digital machinery, and for many years programs for this problem have been available for use on computers of the IBM-CPC variety, and larger. By using special programming techniques, these computations also can be performed on Remington Rand UNIVAC punch-card (series-409) computers, which are small and inexpensive machines designed primarily for business applications.

UNIVAC-409. These computers are plugboard-programmed digital machines that accept input data from punch cards and punch computational results into the same medium. The instructions to guide the machine in computation are wired into one or more sets of plugboards, each of which can accommodate 40 arithmetic operations. The internal memory capacity (6–12 10-digit numbers, depending upon computer model) is quite sufficient for those applications for which the machine was designed, but it is very small compared with the normal requirement of scientific computation.

Card programming. Computation of the two-group eigenvalue equation requires several hundred arithmetic operations and a much larger number of memory locations than are available in these machines. Thus, the usual techniques of plugboard programming do not provide a satisfactory method for solving this problem. We have found it possible to adapt the techniques of card programming to this computer and, as a consequence, have been able to perform the required computations with speed and accuracy.

In card programming, the instructions controlling the progress of computation are contained in a coded deck of cards. With this technique there are no restrictions on the number of computational instructions since the deck is not limited in the number of cards it may contain. Furthermore, the small capacity of the internal memory ceases to be an obstacle since input data and intermediate results can be stored on the very program cards which make use of them.

The adaption of card programming to this computer is possible only because of the nature of the input storage device. During the read-in operation, the reading mechanism examines simultaneously all hole positions of the card. For every hole present a tiny electrical switch is closed and maintained in this condition until the computer operations involving the contents of the card are completed. Electrical plugboard connections to

these switches permit them to be wired into selection networks which, in response to coding in the card, dictate all the elements of a single plugboard instruction. The details of the plugboard wiring and card coding are fairly complicated.*

Experience. The card-programming technique with a UNIVAC punch-card computer has been used at Brookhaven for about a year with satisfactory results. For instance, a rather complete survey of BNL's liquid-metal-fuel-reactor types was performed recently in one evening.

Since large-scale computing facilities are usually available only to larger organizations, it is hoped that the procedures outlined in this note will prove useful to smaller groups that have access to this series of computers.

* BNL-378T69 (1956).

REACTOR FACTS

Nitrogen-cooled-reactor plant costs $356/kw. The $429/kw cost for the City of Holyoke proposed gas-cooled reactor (NU, June '56, p. 96) includes $1.08-million for a separate combustion-fired heater to make it a "dual" plant. Subtracting this from the $6.428-million cost of the plant lowers the 15-Mw nuclear-plant cost to $5.348-million, or $356/kw.

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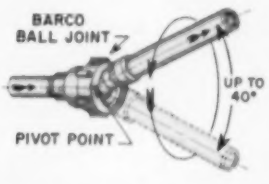

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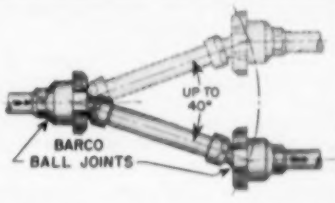

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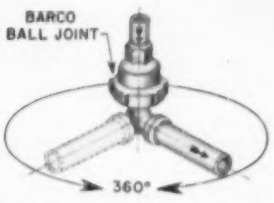

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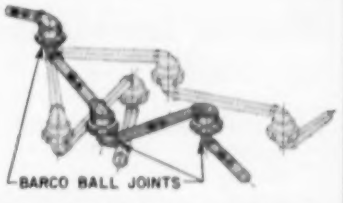

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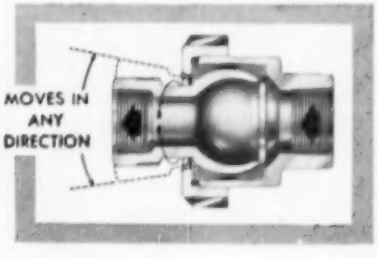

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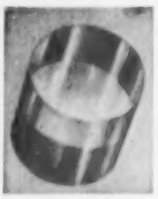
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TECHNICAL ADVANCES

The Free Neutrino Detected for Sure The elusive neutrino seems a lot more real now that it has been definitely detected in the latest phase of the epic experiment by Cowan and Reines of Los Alamos. The theoretical requirements for its existence, to conserve energy and spin in beta decay, have long been accepted, but its low cross section for interaction with matter ($\sim 10^{-44}$ cm^2; mean free path of $\sim$100 light years!) made explicit identification seem virtually unachievable.

Cowan and Reines' experiment depends on the detection of the process of inverse beta decay, $\nu + p \rightarrow \beta^+ + n$. The incident neutrinos come from negatron decay following fission in a Savannah River reactor. The detector consists of three tanks, each 6.3 ft $\times$ 4.5 ft $\times$ 2 ft thick, filled with liquid scintillator (purified triethylbenzene solution of terphenyl and POPOP) and viewed by 110 5-in. photomultipliers. Sandwiched between these three detector tanks are two identical target tanks, 3-in.-thick polyethylene boxes filled with a water solution of $CdCl_2$. The whole is heavily shielded by lead and paraffin and further protected by being deep underground.

Identification of the neutrino through the inverse beta reaction depends on observing, in proper size and time relation, pulses due to the positron's slowing down, its annihilation radiation, and the multiple gamma-ray burst from neutron capture in cadmium after a delay for moderation. Electronic circuits decide when these conditions are realized and gate two triple-beam oscilloscopes to display the (stored) pulses. Manual analysis of the photographed beam traces permits intensive study of the signal and background.

All manner of checks (like substituting heavy water in the target and seeing the signal drop accordingly) and calibrations and 1,371 hours of running time insured that the observed signal was the desired one. The data fit an expected cross section for the inverse process of 6.3×10^{-44} cm^2. Actual counting rate was 0.56 ± 0.06 counts per hour under one set of requirements and 2.88 ± 0.22 cph with revised criteria.

A Look Ahead: High-Temperature Reactors Temperatures in excess of 2,500° F were clearly in sight and gaseous fissioning reactants constrained by electromagnetic fields were a distant possibility as Richard Graham of AEC's Division of Reactor Development peered into his crystal ball at the recent high-temperature symposium sponsored by Stanford Research Institute and the University of California.

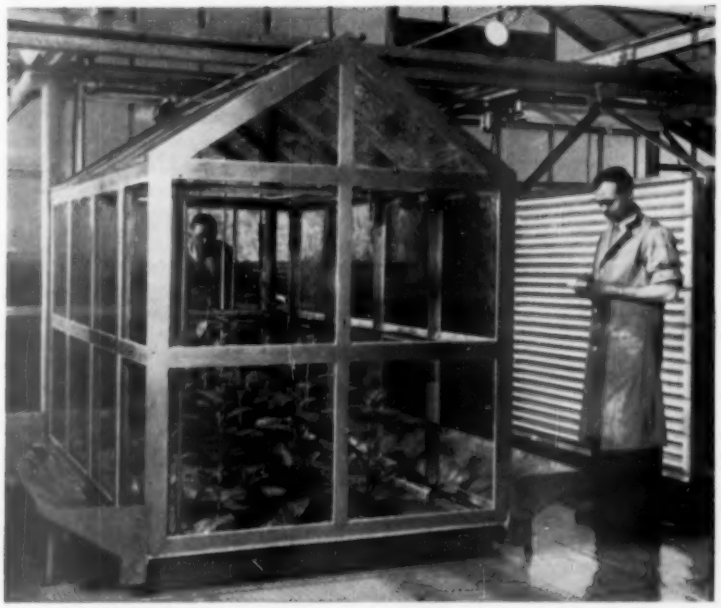
Temperatures of 1,500° F are within the realm of existing technology using liquid-metal-cooled reactors. In AEC's investigations of the possible use of reactors as high-temperature heat sources for chemical processing (e.g., gasification of coal and production of acetylene from natural gas) the target is 2,500° F. It is felt that a reactor using ceramic fuel elements and helium cooling could reach such temperatures.

To go higher, Graham pointed out, one should seek ways to transfer the kinetic energy of fission fragments directly to the working fluid. One way to do this would be to set up thin surfaces of fissioning material at the exit stream so that the coolant could reach temperatures in excess of the reactor. Fission-product contamination of the coolant could be handled by means of decontamination and holdup techniques.

Another approach involves increasing heat-transfer rates—here Graham points to the virtues of the Nernst effect, in which a gaseous molecule dissociates endothermically at the heat-exchanger wall and, upon returning to the process stream, recombines and gives up energy.

Somewhat longer range is Graham's suggestion to confine an ionized gaseous fuel (such as UF_6) and a moderator (if needed) within a vessel by means of electromagnetic fields. This proposal is strongly reminiscent of schemes being pursued in attempts to control thermonuclear reactions (NU, June '56, p. 36). Some interesting comparisons result from the fact that there is no critical size required for a thermonuclear reactor though there would be for a fission chain reactor. Thus the gaseous fission reactants could not be arbitrarily rarefied as in some of the thermonuclear experiments disclosed thus far. Compensating this is the fact that million-degree fusion temperatures are not required.

APPLIED RADIATION



Larry D. Thompson (left) of the American Tobacco Co. and Lovell J. Dewey, biochemist of the Medical College of Virginia, Richmond, inspect the growth chamber of the new isotope farm

Virginia Gets Isotope Farm

Nature will synthesize labeled organic compounds for biochemists of the Medical College of Virginia in Richmond. Their new isotope farm is modeled after the one at the Argonne National Laboratory and is a present from the American Tobacco Co. It cost $120,000. Paul Larson is director; William Stepka is plant physiologist in charge.

Plants in the growth chamber of the "farm" develop in a sealed atmosphere containing $C^{14}O_2$; 40% of the plant's dry weight is carbon that comes from this atmosphere. A few other tracers can also be introduced as radioactive nutrients. These reach the roots in water that is pumped several times a day into the gravel in which the plants grow.

Temperature, humidity. In the sealed chamber temperature and humidity are special problems. The photograph shows the water flowing on external surfaces to control the internal temperature. A thermostatically controlled valve mixes chilled and room-temperature water so as to compensate for varying amounts of heat delivered by sunlight. An automatically controlled dehumidifier removes excess moisture given off by the plants.

CO_2 concentration. CO_2 of the desired specific activity is supplied to the plants as required. Its concentration in the chamber is monitored by an infrared analyzer. Meanwhile an ionization chamber-electrometer system records the level of radioactivity in the atmosphere.

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Vulcanizing by Irradiation

Two-million-volt Van de Graaff electrons make silicone rubber by cross linking the molecules in silicone gum. H. R. Sheppard, E. J. Croop, and G. C. Gainer of Westinghouse have developed the process. It requires no heat, pressure, or chemical additives. Conventional methods use chemicals that eliminate some desirable qualities of the product, especially those required for electrical insulation. Another advantage is the short time required. The new technique produces a better rubber in 2 sec than conventional vulcanization yields in several hours.

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BOOKS

Mesons and Fields—Vol. 1, Fields

By S. S. SCHWEBER, H. A. BETHE, and F. de HOFFMAN (Row, Peterson and Co., Evanston, Ill., 1955, xi + 449 pages, $8.00)

Reviewed by ABRAHAM KLEIN, University of Pennsylvania, Philadelphia, Pa.

The basic theoretical framework in the area of elementary particle physics is the quantum theory of fields, that synthesis of the particle-wave duality in which an attempt is made to understand particles as the elementary quanta of fields. From the very beginning of this discipline in the late twenties, it has been felt that its ultimate aim was to deduce the mass (and charge) spectrum of the particles found in nature. Yet, today, the *modus operandi* of most work remains as modest as heretofore.

After initial consideration of the fields uncoupled to one another, each characterized by a field quantity of particular tensorial or spinorial nature and by the mass of the associated elementary particle, one introduces the interactions between fields in terms of the various coupling constants—electric charge, meson-nucleon coupling constant, etc. The attempt to calculate then discloses the difficulties that must be so amusing to non-specialists: the physical consequences of such theories, the energy levels and scattering cross-sections, are apparently infinite!

The source of these difficulties has been understood for almost a decade now in consequence of the work of Tomonaga, Schwinger, Feynman, and Dyson. Their research demonstrated that for a certain (small) class of relativistic field theories, the infinities could be removed if the distinction was recognized between the mass and charge of bare particles—a mathematical fiction—and that of particles in interaction. What was shown was, in particular, that the power-series solution of the field equations, when expressed as functions of the experimental masses and coupling constants, were term by term finite. The "renormalized" solutions, when confronted with experiment, were in startling agreement, at least for quantum electrodynamics. Although the same can hardly be said for π-meson physics, and still less so for the physics of the strange new particles, where many questions antecedent even to the above have yet to be answered, there then appears to be one field theory, which though fundamentally still unsatisfactory, has nevertheless achieved a temporarily closed status.

It is with the account of this development that Schweber's book is concerned. "Fields" is the first of a two-volume effort, "Mesons and Fields," the second of which, "Mesons," the work predominantly of the other two authors, was the first to appear in print. The two volumes will, in fact, appeal to quite different audiences.

"Mesons" is a critical review of a rapidly changing subject written in the summary style that will be most attractive to the mature physicist, preferably one with some previous knowledge of the subject. "Fields," on the other hand, should be most welcome to the student, who turns for the first time to the quantum theory of fields and is overwhelmed by the profusion of periodical literature of the past decade.

For "Fields" is designedly a simple book. Its core is a full and readable account of the classic papers of Feynman and Dyson on the definition, construction, and analysis of the scattering matrix, leading inevitably to Dyson's proof of the renormalizeability of quantum electrodynamics.

The early sections develop all the standard background material required for an understanding of this work. Although the emphasis in the later chapters is upon the description and removal of the divergence difficulties of the theory, some of the chief applications, as to the Lamb Shift and to the anomalous magnetic moment of the electron, are described in adequate detail, and most of the others are at least alluded to.

The detailed discussion in this book is, with a few exceptions, derived from work published prior to 1952. The more recent promising developments, based entirely upon the study of the field equations and their matrix elements in the Heisenberg representation are summarized in the penultimate chapter. If the object of Schweber's endeavour had been to produce a critical study of conventional local field theories, he might well have made these developments the basis of his exposition rather than its aftermath. On the other hand, there is no doubt that the newer work will be more readily accessible to the reader who has mastered this volume. It is also hardly to the author's discredit that one requires an additional bag of tricks over and above those displayed in "Fields" to cope theoretically with meson phenomena. It reflects, rather, the more difficult character of the latter problem, as evidenced by the even more provisional aspect of the second volume.

The Therapeutic Use of Artificial Radioisotopes

By PAUL F. HAHN (John Wiley and Sons, Inc., New York, and Chapman and Hall Ltd., London, 1956, x + 414 pages, $10.00),

Reviewed by EDITH H. QUIMBY, Radiological Research Laboratory, College of Physicians and Surgeons, Columbia University, New York, N. Y.

Five years ago Dr. Hahn published a book entitled "A Manual of Artificial Radioisotope Therapy," to which 15 collaborators contributed. The present book has a very similar title, but it is in no sense a second edition. It is a completely new book, with 25 new collaborators and none of the old ones. Many of the chapter topics are the same, however, and it is sometimes of interest to have two points of view.

When a book is a collection of individual essays rather than an integrated whole, it is almost inevitable that some parts will suffer by comparison with others, and this is no exception. The introductory chapter by Hevesy is brief; it could well have been more ample, as furnishing background for the rest of the book.

The chapter on radiological physics leaves a great deal to be desired. Only about two pages are devoted to phenomena and units of radioactivity, whereas energy absorption and ionization chambers are discussed in some detail. The chapter on dosimetry is adequate, and includes some interesting practical problems.

The section on availability and procurement suffers heavily from the fact that the Atomic Energy Commission changed its forms and procedures just about when the book was finished. Thus most of the 8 pages dealing with applications are obsolete, and the half-page, last-minute addendum doesn't help much. One might question the propriety, in this chapter, of referring extensively to one secondary supplier and omitting most of the others. The chapter on production and handling is good.

It is in the clinical section that the greatest unevenness exists. Some chapters are essentially papers on the work of the author, with no mention of

anyone else or any other method. Thus the chapter on treatment of leukemia and polycythemia with P^{32} is a good account of a procedure that one group has found successful. Not only is no other method described; it is flatly stated (without supporting evidence) that no other method used at present is as good. This is one man's opinion; it is not the generally prevailing one. If this is a textbook, such a chapter is inadequate.

In marked contrast is the chapter on thyrotoxicosis, where the problem is well analyzed, various points of view presented, and finally, tabulation presented of results collected from the publications of many groups. The chapter on thyroid cancer follows a similar excellent pattern. Admittedly it is more work to review the literature and present a well rounded picture, but for a book under this title, it would appear to be desirable.

It is not obvious why separate chapters should have been devoted to intraperitoneal and intrapleural uses of colloids. Both contain valuable material, though some broader information as to results would have been welcome. It is to be regretted that the only method described for intraperitoneal injection is by means of a shielded syringe, since there are half a dozen variations of gravity-flow methods that are safer and probably wiser. Some informative chapters describe work still mainly in the hands of one or a few groups. Treatment of bladder tumors by isotope in the cavity and of cervix cancer by parametrial injections of radioactive gold are in this group. Chapters on beta-ray applicators and interstitial sources are well developed. The one on telecobalt is brief, but perhaps all that is necessary here.

The book is well printed and illustrated. Useful reference lists are appended to most of the chapters.

Isotope users will find the book interesting and will doubtless consult it frequently. It is not a textbook for a beginner and the experienced therapist will quarrel with some of its contents. Yet both will appreciate it, even as they acknowledge its limitations. It should be accessible to all who are concerned with therapeutic uses of radioactive isotopes.

Geneva Volumes

The following volumes are in addition to those previously published (NU, Feb. '56, p. 76; May '56, p. 118) in the United Nations series reporting the

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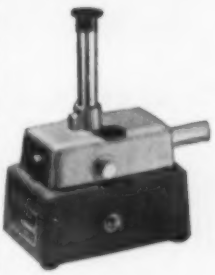

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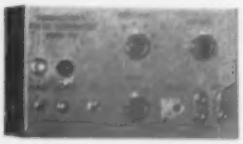

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proceedings of the Geneva Conference on the Peaceful Uses of Atomic Energy.

Vol. 6—Geology of Uranium and Thorium

This volume consists of session 6B on the occurrence of uranium and thorium and 7B on prospecting for uranium and thorium.

Session 6B presented the broadest available survey of world resources of nuclear fuels. Almost all countries at the conference described their resources. Session 7B included discussions on prospecting techniques.

Vol. 8—Production Technology of the Materials Used for Nuclear Energy

The technology of several fuels, moderators, and structural materials are covered.

The sessions included are the treatment of U and Th ores and ore concentrates (session 14B); production of metallic U and Th (15B.1); analytical methods in raw material production (15B.2); heavy water (16B.1); graphite (16B.2); zirconium (17B.1); and beryllium (17B.2).

Vol. 9—Reactor Technology and Chemical Processing

Although this volume begins and ends with sessions on waste disposal, the greater amount of information—and possibly that of most immediate interest—is contained in the middle sessions on metallurgy and chemical processing. Since processing is now one of nuclear power's biggest hurdles, this is one of the most valuable volumes in the series.

Ninety-one papers are presented in these sessions: waste disposal problems (session 7.3); metallurgy of Th, U, and their alloys (18B.1); fabrication of fuel elements (18B.2); handling liquid metals (19B.1); liquid metal heat transfer (19B.2); corrosion in liquid metal systems (19B.3); chemical aspects of nuclear reactors (20B); chemical processing of irradiated fuel elements (21B and 22B.1); separation and storage of fission products (22B.2); ground disposal (23B.1); sea disposal (23B.2); airborne problems (23B.3).

Some of these sessions constituted a major release of U. S. technology, with 6 papers in fabrication, 9 in liquid metals, 5 in chemical aspects, and 16 in chemical processing. In fact, 36 out of the 57 in these sessions are from the U. S.

Volume 10—Radioactive Isotopes and Nuclear Radiations in Medicine

The first three papers of this volume are *Radioisotopes in Medicine, Importance of Isotopes in Biology and Medicine,* and *Importance of Isotopes in Medicine.* These sum up the contents, although some of the other papers are more specifically directed.

Four sessions are recorded in the volume: 7.2 on isotopes in (medical) technology and industry, 8C on radioactive isotopes and nuclear radiations in medical therapy, 9C and 10C on isotopes and radiations in diagnosis and studies of disease.

As it must, the subject matter strays away from the nuclear with papers on X-rays. Similarly there is juxtaposition of subjects essentially unrelated tied together by the thin string of tracer technology. The volume presents 89 papers on internal and external radiation therapy, metabolism studies that use tracers, and tracer studies of such items as lung volume and red cell mass.

Volume 11—Biological Effects of Radiation

In this volume are the papers from sessions 6.1, 11C, 12C, and 13C.1. The subject matter ranges over such topics as radiation studies with animals, modes of radiation injury, genetic effects, effects of radiation observed after atomic bombings, and sickness resulting from reactor excursions.

Four papers by Masao Tsuzuki, director of the Japanese Red Cross Central Hospital, discuss observations that have been made of victims of the bombs dropped on Hiroshima and Nagasaki. A paper by Hasterlik and Marinelli of the USA and one by Guskova and Baisogolov of the USSR discuss observations of acute radiation injury in man caused by chain-reaction excursions.

A total of 67 papers is presented under the following headings: *Biological Effects of Radiation, Modes of Radiation Injury, Carcinogenesis and Metabolism of Bone-Seeking Isotopes, Effects on Reproductive System and on Fetus, Mechanisms of Radiation Injury, Protection and Recovery,* and *Genetic Effects—Human Implications.*

Volume 12—Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology, and Biochemistry

In this volume are sessions 7.2 on isotopes in agriculture, 13C.2 on radiation-induced genetic changes and crop improvement, 14C on tracer studies in agriculture, and 15C and 16C on radioisotopes in physiology and biochemistry.

Among the papers is a survey by the

Food and Agriculture Organization of the United Nations on uses of atomic energy in food and agriculture. There is a variety of metabolism studies—on drugs, steroids, enzymes, etc. One paper is entitled "Studies on Pearl Formation." Another is called "Labelling Locusts with Radioisotopes."

Nearly 100 papers are included.

Professional Engineer's Examination Questions and Answers

By WILLIAM S. LALONDE (McGraw-Hill Book Co., Inc., New York, 1956, 462 pages, $6.50)

Reviewed by WIRT FAIRMAN, Indiana Technical College, Fort Wayne, Ind.

A guide to examinations for the professional engineer license, the land surveyor license, and the engineer-in-training certificate, this book is designed for both the newly graduated engineer and the older practicing engineer. Over 500 questions and problems appearing in this book were taken directly from sample sheets or past professional engineer examinations.

Part one is general information on certifications and contains the addresses of all registration boards. Part two contains questions from professional engineers examinations on chemistry, engineering materials, kinetics and statics, thermodynamics, civil engineering, electrical engineering, engineering economics, mechanical engineering, structural engineering, and land surveying. Part three gives solutions to the problems and questions. Part four has engineering symbols.

There are other aids to these examinations but the lateness and completeness of this one make it very helpful to aspiring engineers.

BOOKS RECEIVED

Molecular Beams, by Norman F. Ramsey (Oxford University Press, New York, 1956, xii + 466 pages, $12.00). *(To be reviewed.)*

Progress in Nuclear Energy, Series 1, Physics and Mathematics, Vol. 1, by P. A. Charpie, J. Horowitz, D. J. Hughes, and D. J. Littler (McGraw-Hill Book Co., Inc., New York, 1956, x + 398 pages, $12.00). *(To be reviewed.)*

Atoms and Energy, by H. S. W. Massey (Philosophy Library, Inc., New York, 1956, 174 pages, $4.75). *(To be reviewed.)*

Nuclear Fuels, by David H. Gurinsky and George J. Dienes (D. Van Nostrand

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Co., Inc., New York, 1956, xvi + 364 pages, $7.50). (*To be reviewed.*)

Reactor Shielding Design Manual, edited by Theodore Rockwell, III (McGraw-Hill Book Co., Inc., New York, D. Van Nostrand Co., Inc., New York, 1956, xii + 481 pages, $6.00). (*To be reviewed.*)

Radiation Dosimetry, by Gerald J. Hine and G. L. Brownell (Academic Press, Inc., New York, 1956, xiv + 932 pages, $22.00). (*To be reviewed.*)

Proceedings: World Symposium on Applied Solar Energy (Association for Applied Solar Energy, 204 Heard Building, Phoenix, Arizona, 1956, 304 pages, $5.00). This book reports the symposium sponsored Nov. '55 by the Association for Applied Solar Energy, Stanford Research Institute, and the University of Arizona. The 30 papers cover economics; utilization of solar energy for high temperature furnaces, heating, cooling, and plant culture; conversion to mechanical energy, chemical energy, and electricity; and architectural problems. The final section is a round-table discussion of the future of applied solar energy.

Quantum Field Theory, by Hiroomi Umezawa (Interscience Publishers, Inc., New York, and North Holland Publishing Co., Amsterdam, 1956, xiv + 364 pages, $9.75). Beginning with some history and discussion of the relativistic field equations, the book proceeds to quantum theory of free and interacting fields. Later chapters cover perturbation and renomalization theories, and theories of damping, *S*-matrix, and propagators.

Automation—Friend or Foe? by R. H. Macmillan (Cambridge University Press, New York, 1956, viii + 100 pages, $1.95). In this survey of the benefits and difficulties to be expected with the coming of age of automatic control, the author takes an optimistic view of automation's future. The chapters discuss the history, design problems, and economics of automation, automatic computers, and future prospects.

Special Functions of Mathematical Physics and Chemistry, by Ian N. Sneddon (Interscience Publishers, Inc., New York, and Oliver and Boyd Ltd., London, 1956, viii + 128 pages, $1.55). This book is intended for students whose interest is in the application of special functions to problems in physical science. Little use is made of the theory of functions of a complex variable. Covered are hypergeometric, Legendre, Bessel, Hermite and Laguerre, and Dirac delta functions.

Paperbound republications (Dover Publications, Inc., New York). Several republications are available: "Hydrodynamics," by H. L. Dryden, F. P. Murnaghan, and H. Bateman (1956, 634 pages, $2.50); "Investigations on the Theory of the Brownian Movement," by Albert Einstein (1956, 119 pages, $1.25); "Asymptotic Expansions," by A. Erdelyi (1956, vi + 108 pages, $1.35); "Experiment and Theory in Physics," by Max Born (1956, 44 pages, $0.60); "The principles of Mechanics," by Heinrich Hertz (1956, 271 pages, $1.75).

Principles and Techniques of Applied Mathematics, by Bernard Friedman (John Wiley & Sons, Inc., New York; Chapman & Hall, Ltd., London, 1956, ix + 315 pages, $8.00). One of the occupational hazards of graduate nuclear physics, having to learn the mathematics of the subject along with the subject matter, may be considerably lessened by such a book as this. The declared purpose is to show that the gap between pure and applied mathematics is illusory and that the study of abstract systems can help in the solution of concrete problems.

The five sections of the text are entitled *Linear Spaces, Spectral Theory of Operators, Green's Functions, Eigenvalue Problems of Ordinary Differential Equations,* and *Partial Differential Equations.*

Topology, By E. M. Patterson (Oliver and Boyd, Edinburgh and London; Interscience Publishers, Inc., New York, viii + 128 pages, 1956). The book is offered as an elementary but rigorous introduction to its subject for undergraduates and graduate students. Its subject matter includes topological spaces, homotopy, simplicial complexes, and homology.

The Structure of Turbulent Shear Flow, by A. A. Townsend (Cambridge University Press, New York, 1956, xii + 315 pages, $7.50). In this book, Dr. Townsend pulls together material on turbulence that has appeared scattered in the literature and provides a unified analysis.

ALSO OF NOTE

Radiation Safety Primer. The AEC Safety and Fire Protection Branch has

prepared an employee training unit for organizations having a radiation hazard. It explains what must be done for the employee and by him. The unit consists of 46 color cartoon slides ($11.50 mounted in cardboard and $18.40 in glass; to learn where available, write Safety and Fire Protection Branch, U. S. Atomic Energy Commission, Washington 25, D. C.), a printed booklet containing sketches of the slides ($0.25 each, 25% discount for 100 or more; Government Printing Office, Washington 25, D. C.; single copies from Safety and Fire Protection Branch), and instructor's handbook ($0.35, Safety and Fire Protection Branch).

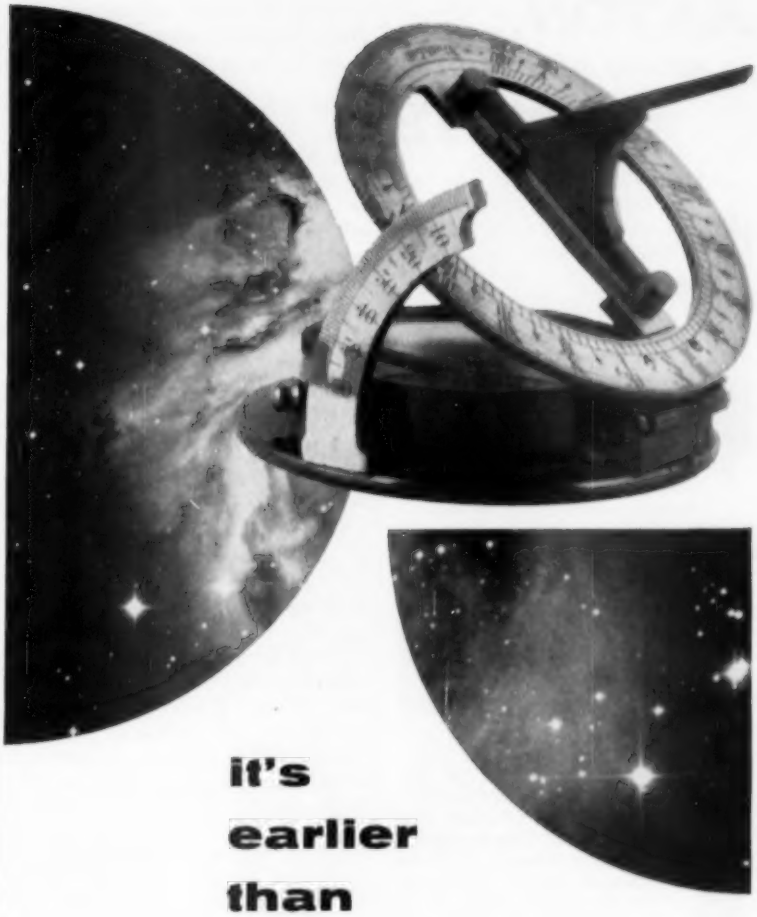
Declassified AEC reports. Technical reports recently released through the accelerated declassification and release program are listed in eight free price lists: TID-1901, -1902, -1903, -1904, -1905, -1906, -1907, and -1908. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Electronics Test Equipment Descriptive Data Sheets. Data sheets for 400 new equipments are being released to add to the 1,100 in the compilation released last year. *Carl L. Frederick and Assoc., 4630 Montgomery Ave., Bethesda, Md.*

Time-Saving Network Calculations. This 120-page monograph, by Harry Stockman, gives a set of general rules for network calculations, and describes the use of Thevenin's Theorem, the potentiometer method, and other techniques for the transient and steady states. Two output immittance theorems are formulated. The symbolic method and Laplace transform are used in many of the solved problems. *SER Co., 543 Lexington St., Waltham, Mass., $1.75.*

Bibliography of Solid Adsorbents, 1943 to 1953. This National Bureau of Standards Circular 566, by Victor R. Deitz, is a 1,528-page survey. It contains author and subject indices. In the subject index, the main heading is based on the type of adsorbent and the subheadings on general aspects of the gas or solution phase. *Government Printing Office, Washington 25, D. C., $8.75.*

Transistors I. This 676-page RCA volume contains 31 unpublished papers, 10 previously published, and abstracts of 46 others. Its six sections are: general, materials and techniques, devices, fluctuation noise, test and meas-



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urement equipment, and applications. *Radio Corp. of America, RCA Laboratories, Princeton, N. J., $4.50.*

Technical Digests. This monthly publication of the Organization for European Economic Co-operation contains digests from 1,000 European periodicals surveyed regularly. The articles selected describe tested processes, methods, apparatus, or materials that can be applied fairly quickly and easily in industry. Some illustrations are included. The U. S. edition is printed in English. *O. E. E. C. Mission, 2000 P St., N. W., Washington, D. C., annual subscription (12 issues)—$24.00.*

Bibliography of Monolingual Scientific and Technical Glossaries, Vol. 1: National Standards. This 219-page UNESCO publication, by Eugen Wüster and a number of collaborators, lists 1,581 national terminological standards publications. Most are monolingual and some interlingual. The bibliography is in French and English with all titles translated into these languages. References are grouped by subject according to the Universal Decimal Classification. *Columbia University Press, 2960 Broadway, New York 27, N. Y., $2.50.*

Industrial Research Laboratories of the United States. The 1956 edition includes information on laboratories of 4,060 companies. Entries give locations of laboratories; research executives; numbers of professional, technical, and administrative employees; and kinds of research. *National Academy of Sciences-National Research Council, Publications Office, 2101 Constitution Ave., Washington 25, D. C., Publication 379, $10.00.*

Industrial Ventilation Manual. This is the fourth edition of the official publication of the American Conference of Governmental Industrial Hygienists. The recommended practices are approved by Federal, state, and municipal government industrial hygiene departments. *Committee on Industrial Ventilation, P. O. Box 453, Lansing 2, Mich., $4.00.*

Self-readers for Navy's dosimeter. Two Navy research reports ("A Portable Reader for DT-60 Dosimeters," PB 111887, $0.50; "A Pulsed-Light Reader for the DT-60 Glass Dosimeter," PB 111977, $0.50) describe portable self-readers for the DT-60 personnel silver-activated phosphate glass dosimeter. The readers weigh 20 and 14 lb,

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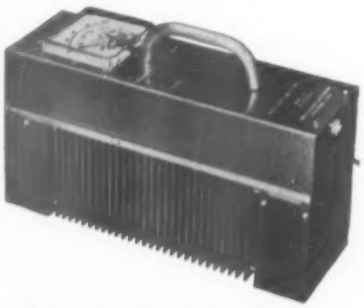

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respectively, and are battery powered. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Public Relations for the Atomic Industry. This 178-page handbook is based on the proceedings of a 2-day conference. It includes papers and discussion on uses of atomic energy, sources of atomic information, public information needs and thinking, and available filmed material on atomic energy. *Atomic Industrial Forum, Inc., 260 Madison Ave., New York 16, N. Y., $3.00.*

Isotope Index. This very useful, 64-page reference has 2,080 entries listing suppliers of 332 isotopes (125 radioactive and 207 stable) and 539 labeled compounds—1,075 C^{14} compounds. Entries include specific activity, cost, delivery time, and supplier. Suppliers services are detailed, and AEC license requirements are described. Scientific Equipment Corp. would like to hear from domestic and foreign suppliers not listed. *Scientific Equipment Corp., 5438 Lowell Ave., Indianapolis, Ind., $2.00 ($2.50 foreign).*

AEC research reports. Reports released through the Office of Technical Services are available in bulk packages for each of the following categories: Health, Physics, Biology and Medicine (220 reports, $74.00); Chemistry (455, $164.00); Engineering (105, $34.00); Geology and Mineralogy (144, $42.00); Instruments (292, $62.00); Metallurgy and Ceramics (380, $92.00); Physics (1,190, $280.00); and Miscellaneous (55, $23.00). *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Quality Control and Applied Statistics Abstracts. The monthly abstracting service will cover world literature (more than 400 journals) on quality control, operations research, and industrial applications of statistical methods. It will consist of a yearly volume of about 1,000 pages. *Interscience Publishers, Inc., 250 Fifth Ave., New York 1, N. Y., $60 yearly.*

Techniques of Plant Maintenance and Engineering—1956. This 248-page book gives 16 papers and 15 roundtable discussions of the conference at the Plant Maintenance and Engineering Show. Among industries getting special attention are chemical plants and petroleum refineries. *Clapp and Poliak, Inc., 341 Madison Ave., New York 17, N. Y., $10.*

Simex . . . an experiment by the Combat Operations Research Group, to test an anti-tank mine simulator, or automatic umpiring device for troop tests or maneuvers. The simulator looks like an actual mine, but emits an electrical pulse that stops the tank without damage or injury. Simex is typical of work done by CORG scientists to assist in developing new tactics and organizations for the Army.

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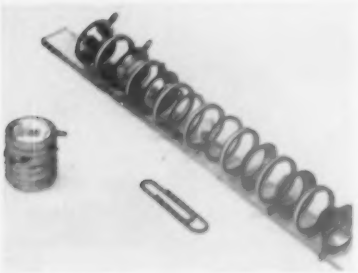

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Ruggedness, long life (20,000 hr), and high-temperature ($\gtrsim$400° F) capability are the outstanding features of revolutionary new ceramic tubes now available. Stacked design permits automatic assembly and construction, which will make prices competitive with conventional types. Already available are a twin-triode electrically equivalent to 6SN7 and a pentode akin to the 6AK5. Two others are on the way and there will be 9–12 when full production is achieved next year.

Radiation hardiness is being investigated in reactor-irradiation tests under auspices of Wright Field Air Development Center.—Eitel McCullough, Inc., San Bruno, Calif.

Low-Level Beta Counter Uses Anti-Coincidence

Specifically designed for low-background counting of medium-energy betas, this unit uses a halogen-filled Anton G-M tube completely surrounded by cosmic-ray counters. Surrounding tubes are operated in anti-coincidence to reduce background.

Electronic unit has high-voltage taps for both sample counter and anti-coincidence ring. Switch selects anti-coincidence counting, sample counting, or ring count. With 2-in. lead shield, background is reduced to ~2 cpm. Efficiency with Y^{90} betas is ~25%.—Isotopes, Inc., 123 Woodland Ave., Westwood, N. J.

LABORATORY INSTRUMENTS AND APPARATUS

Pocket Wire Stripper

Pocket-sized tool strips and cuts wire of various sizes.—Jo-El Co., 14209 Leroy Ave., Cleveland, Ohio.

•

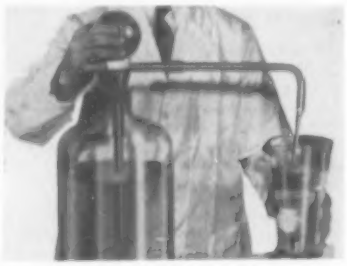
Programmed pulse generator. Arbitrary pulse patterns of negative and positive pulses of variable widths and variable delay can be set up in seconds.—Wang Laboratories, Inc., 37 Hurley St., Cambridge 41, Mass.

Drill logger. Logging system includes portable reel, G-M counter with watertight probe and recorder for uranium exploration. —Mount Sopris Instruments Corp., 1320 Pearl St., Boulder, Colo.

Portable Leak Detector

Model 24-210 is a portable helium leak detector to show the existence or absence of small leaks, to determine the rate of leakage, and to find the leaks. It is said to have sufficiently good vacuum geometry and fast enough pumps so that neither cold nor charcoal trap is required. Available accessories include audio alarm and mobile workstand.— Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Cal.

Thyratron speed control. Variable-speed motor drive consists of d-c motor with thyratron-controlled power supply. Full-load torque is available over speed range of 10:1. Maximum armature current is limited by adjustable control to from 100 to 200% of full load. Reversing is accomplished by a switch with dynamic brake that prevents reverse current until motor is at standstill. Available in 10 to 50 hp sizes, 450 to 3,600 rpm.—Ther Electric Works, 17 S. Jefferson St., Chicago 6, Ill.



Pumps

Siph-O-Pump permits pouring of hazardous liquids without lifting or tilting container. Liquid contacts only inert plastic tube.—E. Machlett & Son, 220 E. 23rd St., New York 10, N. Y.

•

Reactor computer. Especially designed for reactor-power-station kinetics, analog computer is being manufactured for problems associated with gas-filled graphite-moderated reactor stations. Flexibility will allow use in the design of other reactor types.—Elliott Bros., Ltd., Nuclear Div., Lewisham, S. E. 13, England.

Computer components. Mechanical and electrical components used in analog and digital computers are described in brochure. 4 p.—Librascope, Inc., 808 Western Ave., Glendale, Cal.

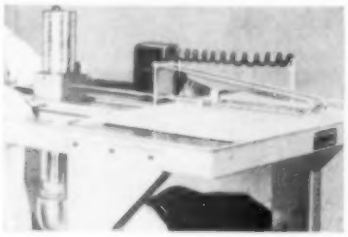
Products Index

Laboratory Instruments and Apparatus 112
Radiation Detectors and Accessories 113
Literature Available 115
Industry Notes 116

RADIATION DETECTORS AND ACCESSORIES

Halogen G-M Tube

DH-1 has a radium-source-gamma sensitivity of 20,000 cpm in a 50 mr/hr field. Operates at 480 volts with a plateau length of 400 volts and shielded background of 3 cpm.—Electronic Associates, Ltd., 4616 Yonge St., Willowdale, Ont.



Medical Scanner

Model 1700 isotope scanner produces a line on paper for each preset number of counts. Instrument may be set to scan an area as large as 14 × 17 in.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.

Neutron Crystals

$Li^6I(Eu)$ crystals for neutron detection are enriched in Li^6 to either 95 or 99%. Available up to 1½ × 1½ in.—National Radiac, 475 Washington St., Newark, N. J.

•

NaI(Tl) crystals. Survey-grade and spectrometry-grade crystals are now being offered.—Fretco Inc., 406 N. Craig St., Pittsburgh 13, Pa.

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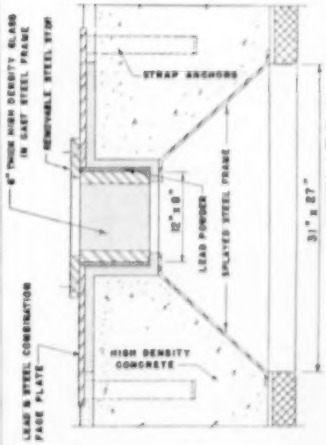

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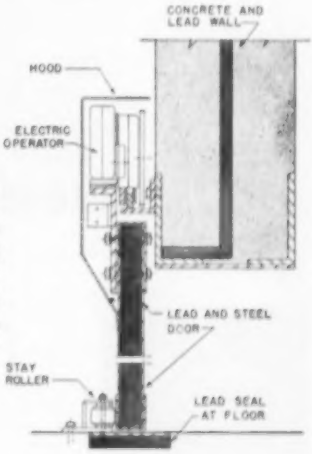

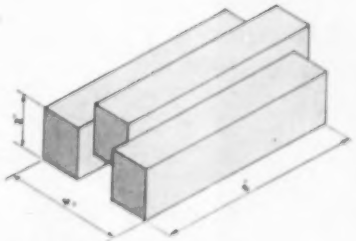

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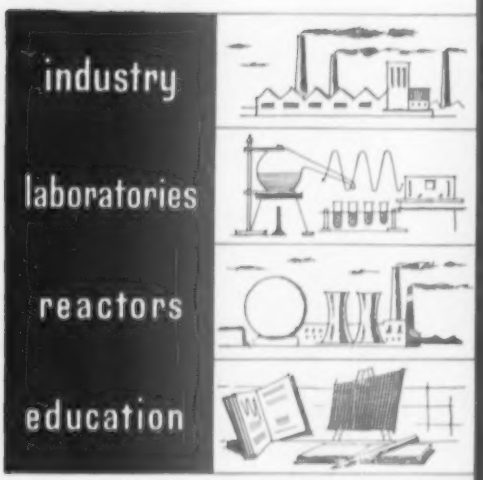

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Survey Detector

Hollow hermetically sealed ionization chamber contains polystyrene beads, charged by shaking, that disappear with exposure to radiation. Two models are calibrated for 25 and 50 r. —Pacific Transducer Corp., 11836 W. Pico Blvd., Los Angeles 64, Calif.

G-M Counter

Halotron portable 15-tube G-M counter is designed for deep-hidden uranium ore and general survey work. Weighs less than 5 lb, is waterproof and shockproof.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

●

Wide-band amplifier. Model 380 offers 70-db gain over frequency range 2–60,000 kc.—Instruments for Industry, Inc., 150 Glen Cove Rd., Mineola, N. Y.

LITERATURE AVAILABLE

Titanium. Six-page paper is entitled "The Drawing of Titanium."—Brooks & Perkins, Inc., 1950 W. 4th St., Detroit 16, Mich.

Drawing. Standards of drawing room practice and simplified drafting are presented in 56-page booklet.—American Machine & Foundry Co., 261 Madison Ave., New York 16, N. Y.

Modular enclosures. Modular system for making up racks and consoles is described. 4 p.—Amco Engineering Co., 7333 W. Ainslie St., Chicago 31, Ill.

Teflon products. Brochure gives details on Chemlon products made of Du Pont Teflon. 12 p.—Crane Packing Co., Dept. ELN, 6400 Oakton St., Morton Grove, Ill.

Instrumentation. Several bulletins give prices and descriptions of nuclear instruments.—Baird Associates-Atomic Instrument Co., 33 University Rd., Cambridge, 38, Mass.

Radio Isotopes. Bulletin 381 describes carrier-free radio-isotope sales program. Entitled "Accelerator-Produced Radio Isotopes." 4 p.—Nuclear Science & Engineering Corp., P. O. Box 10901, Pittsburgh 36, Pa.

Gages. Brochure describes, discusses different types of radioactivity thickness, density gages. 6 p.—Nuclear Corp. of America, Empire State Bldg., New York 1, N. Y.

Isotope applications. Consulting, project research, personnel training, laboratory techniques, and instrumentation are discussed in 20-p. booklet.—Isotopes, Inc., Westwood, N. J.

Handling sodium. Forty-four-page book is entitled "Handling Metallic Sodium on a Plant Scale."—U. S. Industrial Chemicals Co., 99 Park Ave., New York 16, N. Y.

Gaussmeter, magnetic field control. Two 4-p. bulletins discuss Model M-2 precision gaussmeter, and Model C-1 magnetic-field-control system.—Nuclear Magnetics Corp., 154 Boylston St., Boston, Mass.

Ultrasonic cleaning. Several bulletins describe new method of large-scale ultrasonic cleaning.—Acoustica Associates, Inc., Glenwood Landing, L. I., N. Y.

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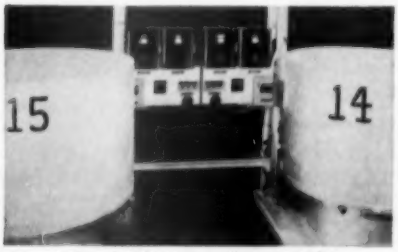

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Dust control. Bulletin 33D illustrates and describes unit for barehand work in a dust-free atmosphere. —Controlled Atmosphere Enclosures Corp., 230–11 141st Ave., Springfield Gardens 13, L. I., N. Y.

Fractionator, Warburg apparatus. Two bulletins, 4 p. each, describe volumetric fraction collector and Lardy Warburg apparatus.—Gilson Medical Electronics, 714 Market Place, Madison 3, Wis.

INDUSTRY NOTES

▶**Jack A. Marinsky** will head the new nuclear department of **Ionics, Inc.**

▶**Edward Shapiro** and **Seymour Rothchild** have formed the new firm, **New England Nuclear Corp.**, 575 Albany St., Boston. It will specialize in the chemical aspects of radioactive materials, labeled compounds, reference sources and radioactivity devices.

▶**Nuclear Corporation of America, Inc.**, N. Y. C., has acquired **Central Sales & Manufacturing Corp.**, Denville, N. J., which will now be known as **Central Electronic Manufacturers, Inc. Charles Baxter, David Trumbull,** and **Bernard Bernstein** have new titles as engineers for **Central Electronic Manufacturers.**

▶**Nuclear Corporation of America** has also acquired **Isotope Specialties Co.** of Burbank, California, as another subsidiary.

▶**Anthony Scala** becomes president of **Chatham Electronic Division** of **Gera Corp.**, succeeding **W. L. Meier,** who becomes director of research.

▶**Vernon L. Brown** and **Harvey De Covnick** have joined the staff of **Radiation Counter Laboratories, Inc.,** Skokie, Ill.

▶**Norden-Ketay Corp.**, has appointed **Joseph Horacek, Jr.**, as Western regional sales manager.

▶**Ray Cooper** has organized **Technical Filter Co.**, 2719 S. Poplar Ave., Chicago, Ill., to manufacture hair filters formerly manufactured by Wilson & Co.

▶**Leeds & Northrup Co.**, Philadelphia, have received contract to design and supply the control system for the Engineering Test Reactor from the prime contractor, **Kaiser Engineers.**

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NUCLEONICS
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(Continued from p. 73)

with Sylvania and Blaw-Knox in combination, with Koppers, with Vitro and with Union Carbide.

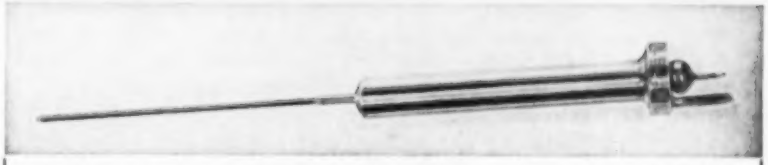
B&W is also fabricating a test loop for insertion in the MTR at the National Reactor Testing Station in Idaho to determine the radiation stability of thorium. Twenty-eight pieces of thorium and of thorium-uranium alloy clad with Zircaloy-2 will be placed in a high-pressure water circulating loop designed to simulate actual reactor pressure-temperature conditions and the assembly will be placed for irradiation of the test pieces to 10,000 Mwd/ton. Then the samples will be examined for dimensional stability, hardness of the clad, density of the "meat," and the "meat"-to-clad bond. These tests will be completed in the middle of 1958.

On the community relations front, Con Edison has launched a speakers bureau program to reach local groups. The company's message is primarily informational and the presentation includes use of a Geiger counter. Cooperating with the local school system, the company has prepared non-commercial booklets on nuclear energy for school use and will serve as host this fall for a teachers' seminar on nuclear energy.

An opinion survey of the company's customers in December, 1955, showed that 22% of the company's consumers (29% in Westchester County) had some idea of the Indian Point development; 84% of this informed group thought it was a good idea for Con Edison to go into the nuclear electric business; 10% had no opinion and 6% thought it was not a good idea.

When this informed opinion was diluted by adding in the uninformed, the Indian Point project was identified as a good idea by 60% of the sample. The company interpreted this survey as calling for a stepped-up nuclear information program. The theme of nuclear energy will be used in the company's advertising program and publicity opportunities will be solicited.

Local and State officials have been kept informed of progress on the Indian Point plan. New York State has set up a Council on the Use of Nuclear Material, headed by Commerce Commissioner Edward T. Dickinson. This group is responsible for coordinating State activities. On March 15, 1956, Industrial Code No. 38 of the State Labor Department and Chapter 16 of the State Health Department's Sanitary Code, both dealing with atomic matters, became effective.



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LETTERS

"Hot" Shipment Containers

DEAR SIR:

The letter by Mr. L. E. Preuss in the May issue of NUCLEONICS (p. 142) on "'Hot' Shipment Containers" was of considerable interest to me since his letter leads me to believe that many recipients of radioisotopes do not fully appreciate the problems encountered in shipping radioactive materials.

While I am not completely familiar with the great variety of containers presently used by other distributors, I can mention some of our problems. Other distributors undoubtedly have similar problems.

Other than safety considerations, the two most important factors that influence the design and use of containers are the cost of container fabrication and shipping charges. Although Mr. Preuss did not mention costs, they are relatively high and important to most customers since the costs must ultimately be borne by the customer. Conveniences are sometimes sacrificed to hold down these costs.

Our customers probably experience the greatest amount of trouble in opening some of the obsolete returnable containers that are now almost ten years old. Some of the containers are kept in use because the expense of replacement could be justified only over a long period of time although we now have better designs. New ideas and design changes come faster than the containers can be altered or new ones built.

Customers may also be interested in knowing that most of our present containers of improved design did not meet the specifications given in the ICC regulations in effect at the time the containers were built. Special Bureau of Explosives permits had to be obtained for their use. The design, approval, and fabrication of new containers often requires more than one year. Incidentally, the original ICC regulations were based upon our first containers (which we now consider poorly designed and obsolete). Any inconvenience we may now suffer is a result of our early lack of experience and is not attributable to the Bureau of Explosives regulations.

We are not unmindful of the customers' problems, and in fact we go to the extent of including bottle-opening tools, wrenches, and can openers with the package—items that customers themselves would normally be expected to furnish. However, we do not furnish all of these tools with disposable containers, since some are too expensive to be disposable and their return would increase inconvenience and expense.

The screw-type closures on some shipping containers may be troublesome but they are required by the ICC regulations in the case of extra hazardous materials for containers less than three inches in diameter. A flanged closure must be used on containers more than 3 in. in diameter. Elimination of a screw-top closure by enlarging the containers would make opening more difficult and would increase the shipping charges to the customer. The screw and flange-type closures are apparently required by the ICC to make the containers as leak-proof as possible and to protect the public by making tampering in transit more difficult.

Because of great differences in customers' needs and handling facilities, we can hardly hope to design packages completely satisfactory to all customers. A nonreturnable lead core in a returnable container, as suggested by Mr. Preuss, might be practical and economical for some radioisotope users. But I am sure others would have no use for the lead and would be unwilling to pay the extra charges since it would eliminate only a portion of the cost and not the trouble of return.

Some customers have found it most convenient and economical to build their own shipping containers to suit their particular needs. The only requirements are that the containers meet ICC specifications and that they can be handled with the supplier's loading equipment. We are always willing to review container designs and to assist in any way we can.

—E. J. WITKOWSKI
Operations Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

DEAR SIR:

Mr. E. J. Witkowski's comment relating to the letter on "'Hot' Shipment Containers" is pertinent in that it evidences that the organization (AEC) that has been most progressive in this matter has also taken the interest to answer this letter, which was, largely, directed at the secondary supplier.

Editing of the original letter for brevity extracted two sentences that read: "It is to the *secondary supplier* that the following (i.e., comments on packaging) is primarily directed, since it is likely that a simple *lack of communication* between recipient and supplier is the basis for this situation" and "Standardized packing procedures for step-wise activity increments *agreeable to all secondary suppliers.*" Subtraction of this left the impression that the comments were directed largely to the AEC Isotopes Division. This was not the original intent.

The note was written from the point of view of the small isotope facility, carrying on an intense and varied program with minimum facilities where instrumentation and disassembly problems are difficult and time consuming. A large proportion of isotope users fall into this "small lab" category—the exception being the few very large government or industrial laboratories.

Mr. Witkowski's note infers that some shipment regulations have undergone a metamorphosis to fit circumstance and experience. This is as it should be. This laboratory has within the week received an improved AEC container design demonstrating the forward-looking attitudes of this group. Designers of radioactive packaging should not be tied to legal rulings that only provide criteria for safe transport, but laws also should prescribe for safe and trouble-free disassembly.

We all bow to the factor of cost. However, short cuts in the initial design of returnable containers are single-shot savings that are attenuated over many deliveries and thus saving per shipment to the recipient becomes minuscule. Extra time spent and instrumentation expended in the disassembly of these containers may exceed many times the initial cost of the entire packaging. In the last analysis this cost is borne by the user.

Local and federal regulations logically should be reviewed periodically to take advantage of the pertinent increased experience and knowledge as it accumulates. Designwise, equal consideration should be given to packaging needs, transport safety, and disassembly techniques.

The initial note's prime purpose was to better communication between packer and recipient. Understanding and co-operation between the groups will best improve the safety and efficiency of handling shipments.

—L. E. PREUSS
Isotope Laboratory, Physics Department
Edsel B. Ford Institute for Medical Research
Detroit 2, Michigan

NEWSMAKERS

John C. Simons, Jr., has joined the staff of National Research Corporation as director of applied physics in the firm's research division; he will be responsible for long-range product development for the equipment division as well as for special projects for research. He had been three years with Westinghouse atomic products division, in charge of control systems and techniques for power reactors.

Arthur D. Little Inc. has elected **William A. W. Krebs** a vice president. Already a director and secretary of ADL's affiliate Nuclear Metals Inc., he is also executive secretary of the New England Committee on Atomic Energy and visiting professor at MIT's school of industrial management.

Paul F. Genachte, acting director of Chase Manhattan Bank's atomic energy division since last year, has been confirmed as director. He worked with former director **Lawrence R. Hafstad** to organize the division.

Rudolph Furrer, vice president in charge of manufacturing and engineering of ACF Industries and president of the nuclear energy products division of ACF, has been elected to the board of ACF.

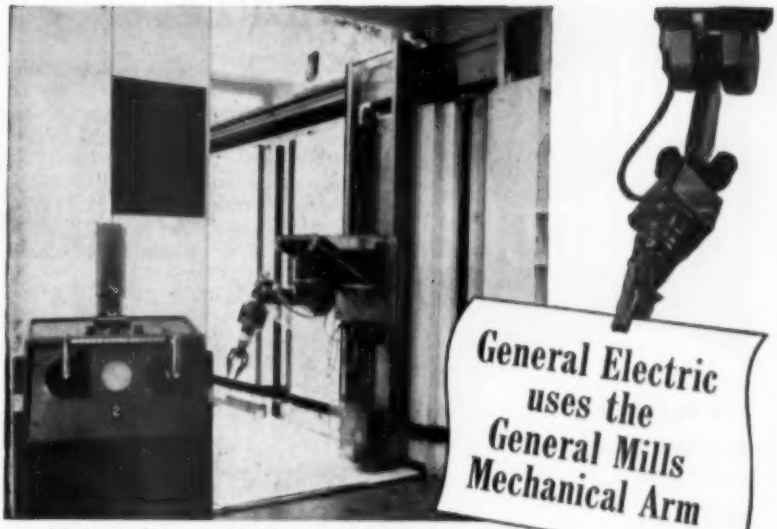
John J. Downing, former chief of the nuclear materials branch in AEC's Chicago operations office, has joined Technical Operations, Inc., as operations-research analyst.

Irvin G. McChesney, Rochester Gas & Electric's representative with Atomic Power Development Associates who has worked on the Detroit fast breeder project for three years, has been promoted to manager of nuclear research.

Thoma M. Snyder has been named manager of research (formerly the technical department) at Knolls Atomic Power Laboratory. From 1947–52 he led KAPL development of the critical-assembly method of nuclear design. In 1943–45 at Los Alamos he had worked on the nuclear design for the first A-bomb, and before that, at Princeton on early development of the first graphite reactor and on isotope separation.

GE also announced four new appointments in the manufacturing section of its atomic power equipment department. **John N. Boyle** will be superintendent of manufacturing; **K. W. Kepner** will be manager of manufacturing engineering; **G. R. MacDonald** manager of materials; and **Leslie C. Pierson** manager of quality control.

Richard Graham, AEC expert on reactor safety and inspection, has joined the Lockheed missiles group at Palo Alto, Calif., as nuclear engineer.



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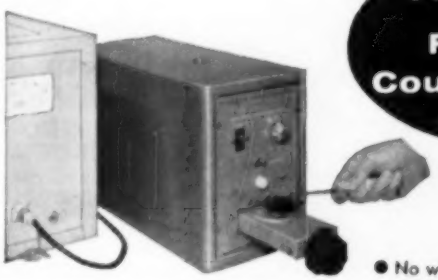

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NUCLEAR CALENDAR

Sept. 13–15—Workshops on legal problems of atomic energy (University of Michigan Law School), Ann Arbor. Five workshops on state regulation for public health; liability for radiation injuries; licensing and AEC control of nuclear enterprise; international legal problems; patent problems. Contact Dean E. Blythe Stason, U. Mich. Law School, Ann Arbor.

Sept. 17–21—Eleventh annual international instrument-automation conference and exhibit (Instrument Society of America), New York (*Coliseum*). Contact Fred J. Tabery, 250 W. 57, NYC.

Sept. 17–21—Second Pacific National Meeting, Am. Soc. for Testing Materials (ASTM), Los Angeles (*Statler*). On 20th, symposium on radiation effects on materials including radiation facilities and mechanics of testing, graphite and fuel materials, structural materials, organics. On 21st symposium on radioisotopes. Apparatus exhibit will show latest in research and testing equipment. Contact Fred F. Van Atta, ASTM, 1916 Race St., Philadelphia 3.

Sept. 25–27—Atomic Industrial Forum, annual meeting, Chicago (*Morrison*). Second annual Trade Fair of the atomic industry **Sept. 24–28**, Chicago Navy Pier. Contact D. J. Scherer, AIF (see above).

Oct. 8—Effects of Radiation in Metals, nuclear metallurgy symposium, at AIME Institute of Metals annual meeting, Cleveland (*Carter*). Contact R. W. Shearman, AIME, 29 W 39, NYC 18.

Nov. 7–9—Ninth annual conference on electrical techniques in medicine and biology (AIEE, IRE, ISA) New York (*Governor Clinton Hotel*). Will include field trips to installations of interest. Contact E. Dale Trout, General Electric Co., X-Ray Dept., Milwaukee 1, Wis.

Nov. 22–23—Symposium on Calder Hall nuclear power plant (British Nuclear Energy Conference), London. Contact A. McDonald, Sec'y, Inst. of Civil Engineers, 1–7 Great George St., London S.W.1.

Nov. 25–30—Annual meeting ASME, New York (*Statler*). Three technical sessions will be devoted to nuclear engineering. Contact B. R. Prentice, ASME, 29 W 39, NYC 18.

Nov. 26–30—Twenty-second National Power Show (ASME), New York (*Coliseum*). Will include enlarged nuclear power display section. Contact ASME, 29 W 39, NYC 18.

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Physical Review Jan. 1, 1947 to Dec. 15, 1955 and/or Reviews of Modern Physics Jan. 1, 1947 to Oct. 1953, unbound, for sale to highest bidder. PA-2125, Nucleonics.

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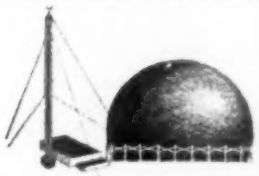

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INDEX TO ADVERTISERS

AUGUST 1956

American Time Products, Inc. 78
Anton Electronic Laboratories, Inc. 110
Assembly Products, Inc. 111
Atomic Industrial Forum, Inc. 9, 10
Atomics International, a div. of North American Aviation, Inc. 24 96
Baird Associates-Atomic Instrument Co. . . . . 3rd Cover
Barco Manufacturing Co. . . 101
Blickman, Inc., S. 3
Byron Jackson Pumps Inc., a Subsidiary of Borg-Warner Corp. 81
Carlson, Inc., G. O. 17
Central Research Laboratories, Inc. 93
Century Electronics & Instruments, Inc. 23
Chromium Corporation of America 102
Convair, a division of General Dynamics Corp. 7 103
Crane Packing Company . . . 87
Crossroads Marine Disposal Corp. 116
Delta Chemical Works, Inc. . 116
Detectolab, Inc., an affiliate of Borg-Warner Corp. . . . 95
Eberline Instrument Division of Reynolds Electrical & Engineering Co., Inc. 13
Ekco Electronics, Ltd. 83
Flanders Mill, Inc. 117
Fluke Mfg. Co., Inc., John . . 86
Ford Instrument Company, Division of Sperry-Rand Corp. 25
General Electric Company . 4, 5 28 2nd Cover
General Mills, Inc., Mechanical Div. 119
International Nickel Company, Inc. 20
Isotope Developments, Ltd. . 114
Kollmorgen Optical Corp. . . 120
Kruger Instruments, Harold . 110
La Roe Instruments, Inc. 116
Leighton Laboratories, H. W. 117
Linde Air Products Co. 114
Lindsay Chemical Co. 90
Lockheed Aircraft Corporation, Georgia Division . . . 21
Lockheed Missile Systems Div. 106

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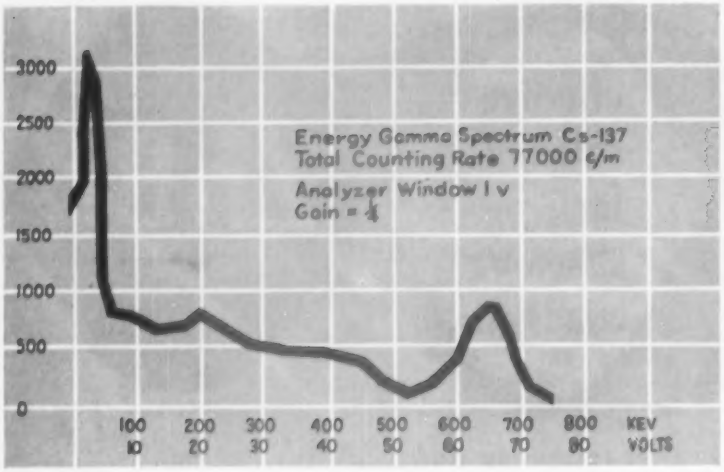

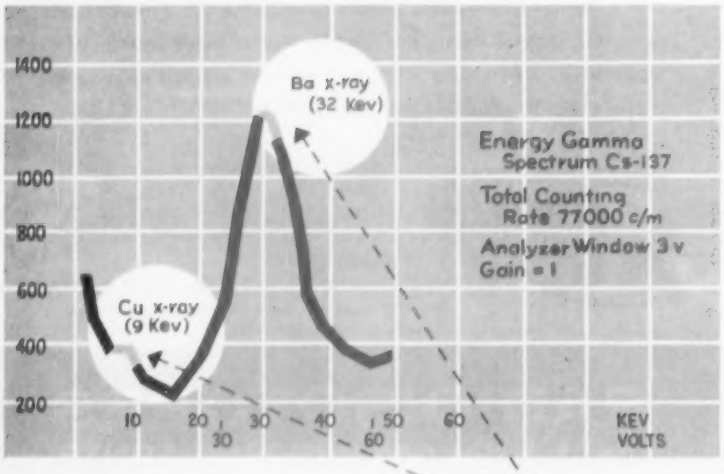

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Los Alamos Scientific Laboratory 14, 15
Mallory & Co., Inc., P. R. . . 6
Martin Co., Glenn L. . . . 99, 109
McGraw-Hill Book Co. 97
Michigan Chemical Corp. . . 125
Minneapolis-Honeywell Regulator Co., Industrial Div. 4th Cover
N R C Equipment Corp., a Subsidiary of National Research Corp. 11
National Lead Company . . . 27
National Radiac, Inc. 108
New England Nuclear Corp. 117
Nuclear Development Corp. of America 18
Nuclear Enterprises, Ltd. . . . 102
Nuclear Instrument & Chemical Corp. 85
Nuclear Measurements Corp. 119
Parsons Company, Ralph M. 77
Penberthy Instrument Co. . . 120
Pergamon Press, Inc. 26
Powell Company, Wm. 22
Pratt & Whitney Aircraft, Div. of United Aircraft Corp. 92
Radiation Counter Laboratories, Inc. 19
Radiation Detection Company 120
Radiation Instrument Co. . . . 106 110
Radiation Instrument Development Laboratory 126
Ray Proof Corporation 113
Republic Steel Corporation . 12
Resistoflex Corp. 107
Searchlight Section . . . 121–124
Solar Aircraft Company 16
Sorensen & Company, Inc. . 94
Special Screw Products Co. . 84
Technical Operations, Inc. . . 82 111
Thermal American Fused Quartz Co., Inc. 91
Thermo Electric Co., Inc. . . . 115
United States Radium Corp. . 125
Victoreen Instrument Co. . . . 105
Westinghouse Electric Corp. 100 111
Weston Electrical Instrument Corp. 8
Where To Buy 120

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 121–124

EQUIPMENT
(Used or Surplus New)
For Sale 120

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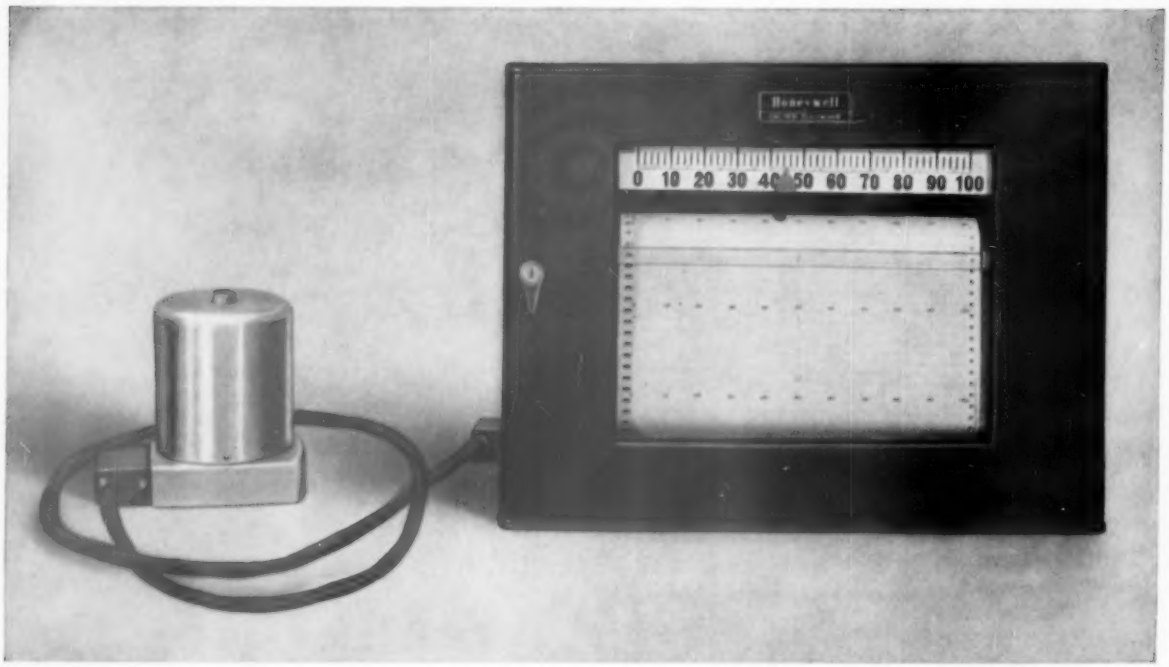

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